DECLASSIFYING DECOMPOSITION: ESTIMATION OF THE POSTMORTEM INTERVAL USING TOTAL BODY SCORE AND ACCUMULATED DEGREE DAYS

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2017

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To life, death, and pursuit of justice and truth. “Every man’s life ends the same way. It is only the details of how he lived and how he died that distinguish one man from another.” – Ernest Hemingway

ACKNOWLEDGMENTS

This work would not have been possible without the financial support of the University of Florida Maples Center for Forensic Medicine and the American Society for the Prevention of Cruelty to Animals whose partnership provided the fellowship that allowed me to complete this research project. I owe special thanks to Dr. Jason Byrd, my co-chair, mentor, and friend, for his continued guidance through my academic studies and research endeavors. My career would not be where it is without his support and for that I am particularly grateful.

I am additionally grateful to my committee members, Drs. Michael Heckenberger, Michael Warren, and Bruce Goldberger for their guidance and assistance throughout my research project and the writing of my dissertation. Further acknowledgment is owed to the undergraduate interns who helped me with my daily data collection: Kyle Campbell, Alex Gillette, and Kelly Schuh. They accompanied me on the arduous forest trips in extreme heat, freezing cold, and pouring rain without hesitation or complaint for three semesters. Their dedication to this study was instrumental in its successful completion.

Finally, I am grateful to all the members of the forensic science and law enforcement communities with whom I have worked over the years. The opportunities that have been provided to me to participate in casework and the relationships fostered in classes and trainings have been invaluable in developing my knowledge and growing my passion for the forensic sciences. For this, I offer my deepest and sincerest thanks.

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Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

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December 2017

Chair: Michael Heckenberger
Cochair: Jason Byrd
Major: Anthropology

Postmortem interval (PMI) is one of the most frequently asked questions in a death investigation as it plays a large role in investigative techniques. However, despite its importance, it is a question which can be answered with a low degree of accuracy due to innumerable variables which affect the ability of investigators to narrow down time since death. Additionally, decomposition is traditionally a qualitatively assessed process which contributes to the difficulty in accurate assessment. This study seeks to improve the methods used for estimating PMI in a decomposition case by attempting to quantify the process of decomposition and standardize the time it takes to reach different stages of decomposition using thermal units rather than calendar days. This study uses total body score (TBS) which quantifies stages of decomposition independently in three body regions (head, torso, limbs/extremities). Accumulated degree days (ADD) are used in this study to associate TBS with the time it takes to reach each stage of decomposition in thermal units within a 24-hour period of time. Degree of decomposition was assessed and TBS assigned throughout the course of three trials using pigs as proxies for human decomposition. Ambient temperatures were

recorded throughout the decomposition process and compared to temperatures from the nearest certified weather station. Both the research site and certified temperatures were used to calculate ADD and were plotted against the TBS for each specimen. An exponential relationship between TBS and ADD was demonstrated throughout the study, but the most reliable equations of prediction were generated when data from each trial were assessed independently from other trials. This demonstrates the major affect that temperature shifts (i.e., hot-to-cold vs. cold-to-hot) and precipitation have on the process of decomposition. As a result, a universal equation to predict PMI based on TBS and ADD is inappropriate, and a more effective solution is the use of an equation that best simulates the environmental conditions closest to those surrounding the investigation. Establishing a standardized method of PMI assessment that can be applied to any decomposition investigation allows for an unbiased evaluation of any victim, regardless of the circumstances surrounding their death event.

CHAPTER 1
INTRODUCTION

Project Overview

Decomposition and the postmortem interval (PMI) are topics that have been of interest to modern forensic investigators for many years. Although there have historically been various methods used without much consistent success – particularly in the case of an extended time since death – newer methodologies that seek to better quantify time since death have only been researched within the last decade. The experimental study portion of this dissertation was designed as a way to better estimate the postmortem interval – or time since death – in death investigations involving human decomposition. While this may seem to be a straightforward concept, the ability to assess time since death based on decomposition has proved difficult as many of the methods commonly used by law enforcement officers or crime scene investigators are based on qualitative observations of the degree of decomposition. Within the scientific community there is not a unanimous consensus on the number of stages of decomposition that a body goes through; some say there are as few as four while others suggest there are six or more distinct stages of decomposition. Generally speaking, degree of decomposition has been assessed using these five stages: fresh, bloat, active decay, advanced decay, and skeletonization – the distinctions for which were based on visual observations of the state and stage of decomposition of the remains (1). This is problematic because it clearly lends itself to bias in observation and interpretation. Indeed, even in this dissertation research the methodology deviates from the five-stage pattern of decomposition to, instead, utilize a four-stage scale as it allows for more specific sub-category assessments to be made within each stage. However, this is just one example of the difficulties that lie within the use of a qualitative method of decomposition assessment. In an effort to alleviate this problem and work to eliminate the observational and interpretative biases that may be present in such assessments, this dissertation research established a quantitative method to assess degree of decomposition through the use of total body score. By associating a numerical value with a specific description of individual and progressive states and stages of decomposition, total body score is a way to alleviate observational and interpretive bias in decomposition assessment. Delineations that represent a progression through the stages of decomposition based on specific descriptions of the condition of the body allow even an investigator who is relatively unfamiliar with the complex processes of decomposition to make a numerical assessment of the state of decomposition which can, then, be used in conjunction with temperature data to provide an estimation of time since death.

Literature Review

The first study addressing a way to better estimate the postmortem interval in decomposing human remains was published by Megyesi et al. in 2005 in the *Journal of Forensic Science* and presents the methodological basis for this and other studies of its kind. The Megyesi project utilized accumulated degree days (ADD) as a method for standardizing temperature and total body scores (TBS) to quantify the degree of decomposition. However, no field research was done in this study. Rather, it utilized 68 cases of human decomposition with known dates of death. Crime scene photographs and temperature data were consulted to determine TBS and ADD, respectively. It demonstrated that an assessment of temperature is necessary for a more accurate estimation of postmortem interval. The greatest value of this study was in the tables that established total body score based on qualitative descriptions of degree of decomposition (2).

Another article that was influential to the established methodology for this dissertation research was published by Sutherland et al. in 2013 in *Forensic Science International* and is most similarly related to the field research portion of this dissertation research project. It, again, used ADD and TBS to better determine postmortem interval, but addressed the variable of body size in its research. Small and large pigs were used; 15 small pigs and 30 large pigs were obtained for research, but only 15 large pigs were used for data collection. Pigs were observed three times weekly for a period of three months during spring and early summer. The same scoring method as the Megyesi et al. study was used and further concluded that temperature plays a large role in decomposition, but that size is also an important factor to consider as smaller pigs decomposed faster than larger pigs (3). It is for this reason that pigs of varying but closely standardized sizes were used in the current study.

In addition to the two studies briefly explained above, 29 additional published articles were used to shape the understanding of the association between decomposition, postmortem interval, and temperature. Insects were a primary consideration in many of these articles as forensic entomology is traditionally the best method to estimate PMI more than 72 hours after death. However, it was not a primary consideration in the current study beyond the utility of ADD which is a concept proven to be both effective and accurate for standardizing temperature against time in a PMI estimation scenario. Of the 31 total articles, nine addressed both accumulated degree hour and total body score together in their assessments of postmortem interval, though not all specifically used those terms (2, 3, 4, 5, 6, 7, 8, 9, 10). These were the articles that were utilized to better understand flaws and modifications to the methodology and variables that would affect the results. Separating out these two main ideas into independent areas of assessment, nine articles addressed temperature as it relates to death in a general sense, but primarily focused on insects. Degree of decomposition and/or postmortem interval was addressed in 11 articles, but only two of these articles also addressed temperature. It is an important distinction that these articles are not methodologically similar to the ADD/TBS articles in that they did not utilize total body score to determine degree of decomposition. Rather, they spoke only in general terms or utilized qualitative measures of decompositional state such as fresh, bloat, early decay, advanced decay, etc. In total, 17 articles discussed one of the two topics of either temperature or degree of decomposition which helped to expand the knowledge base for one portion of the current methodology (11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27).

Looking at the species of specimen used for research, 15 articles utilized pigs in their research, whereas five utilized humans. Two articles utilized both pigs and humans which validates the appropriate utility and association of pigs as a research substitute for humans for decomposition research. In particular, the focus of these articles included insect colonization and insect succession which is important because traditional animal scavengers were excluded from the current study with the exception of insect colonization. A recent study was conducted and published about in the *New York Times* that suggested pigs were not a suitable substitute for human decomposition due to the differences in scavenger preference (28). The current research study does not include animal scavengers for this reason; thus, the two articles associating pigs and humans with insect succession proves that they are suitable as insects prefer pigs and humans equally as an opportunity for carnivorous infestation (29, 30). Within the 31 articles utilized for the methodological establish in the current study, only two addressed actual human decomposition case studies (3, 13). This suggests more research validating the methodology with human decomposition cases (i.e., forensic casework) is necessary in the future. A final consideration for the methodological structure of the current study is location. Very few studies focused on the climate and/or regional differences when addressing PMI estimation. Studies of this nature were conducted in Canada, Australia, South Africa, Malaysia, Thailand, Brazil, Western Europe, and the United States (3, 4, 9, 11, 12, 20, 31). Within the United States, studies were published based on research conducted in Texas and Tennessee (6, 8). This makes evident the importance of conducting research in different climates and temperature regions such as Florida.

Overall, the literature suggests that research of this nature is both plausible and useful for establishing a more accurate method to predict postmortem interval. Though not all studies addressed both temperature and rate of decomposition, the ones that did had the most statistically significant and accurate results, particularly when validating the methods used in one study with those that had been previously published. This dissertation utilizes total body score and accumulated degree day, very similar to the methodology used in the Megyesi and Sutherland studies, but with specific modifications to each. The literature review has shown that temperature should not and cannot be ignored when attempting to determine a PMI estimation. Furthermore, degree of decomposition is best utilized when quantified more specifically than a qualitative explanation of the state of decay; that is, using total body score is better than simply addressing stage of decomposition based on visual observations.

Historical Overview

The subdisciplines within the forensic sciences have long and varied histories, some whose origins were very similar in scope and application to the forms they take today and others that have morphed into their current forms through many years of growth and change. In a death investigation context, forensic investigators rely on specialized knowledge and skills in their everyday jobs – specializations that come from decades of scientific research constantly building on previous studies and expanding from its historical roots. But, it would be irresponsible to ignore the roots from which these new and highly focused disciplines arose. Historically, people have been interested in cause and manner of death determination for centuries, with some of the earliest documented cases originating from 13th century China in *The Washing Away of Wrongs*. In this example, a villager was killed using a common farm implement that most of the villagers possessed. The investigator and author of the text, Sung Tz'u, used his knowledge of insect activity and the commonality of the weapon in question to solve the murder. He requested all the villagers to gather together in the heat of the day with their sickles and hypothesized that insects would be drawn to the one used in the murder due to the remnants of blood and tissue on the blade (31). Moving forward from this very specific example, death investigation has always been a source of mystery for doctors and scientists as the question of time of death is often elusive. It is pervasive in all societies; no one escapes death. Yet, despite its universal nature, there is no clear universal answer to the question (6). The relationship between science and culture with regards to death investigation has been complicated and ever-changing throughout the centuries. Attempts to better understand death – its causes, things that mimic death, and ways to determine its timeline – have baffled even the most astute scientists and physicians. Even Andreas Vesalius, known by many as the father of modern anatomy, struggled with a clear concept of death determination as evidenced by his 1564 autopsy of a still-living individual. It was this mishap that led to the requirement of official pronouncement of death by a physician prior to autopsy (32).

From that point forward, many aspects of the human consciousness were harnessed in an attempt to more effectively determine death, ranging from insensibility, insensitivity, body temperature, respiration, and circulation, though most measure were met with minimal success. Dr. Jacob Winslow, a French anatomist in the 1700s who was credited with being one of the first to publish descriptive anatomy and to question the signs of death in individuals, practiced a method of determining death by arranging women around the corpse and having them weep, wail, and gnash their teeth. He instructed these women to, "If possible, shock the ears by hideous shrieks and excessive noises," theorizing that any living person would be so overcome by the noise that they would wake up and demonstrate their living state (33). Moving from insensibility to insensitivity, Dr. Jules Antoine Josat invented a gruesome instrument in 1850 – a pair of forceps with sharp claws that pinched into the nipples – that was designed stimulate such pain that a person in a state of deep rest would awaken; he also thrust long needles under the fingernails of his patients to determine if they were deceased. This practice, however, was disproven by hysterical patients in a catatonic state (34). Dr. Paul Brouardel, a professor of medical jurisprudence and member of the

Royal College of Physicians of London, published a lengthy manuscript in 1902 detailing methods of death determination up to that point – both successful and unsuccessful – as well as descriptions of their utility in medical practice. These methods included Mayor's Hammer where a hammer was dipped in boiling hot water and pressed to the breast of the patient, Brouardel stating that, "It is an excellent means of reviving a person who has fallen in a state of syncope," and that "The worst that can happen is that it forms a bulla on the place where the hammer has touched," indicating his knowledge of the faults in this method.

Body temperature was also recognized as potentially useful in death determination; however, its precision was nothing short of abysmal. Necrometers were the instrument of the time, but were only calibrated into markers of "alive, probably dead, and dead." Brouardel's final prominent method for death determination – the mirror test – was quite simple; all one has to do is fog a mirror. However, he did make the caveat that "abolition of respiration is the most untrustworthy of all the signs which have been invoked; you know the test of placing a mirror before the lips of a corpse." In the same text, Dr. Brouardel referenced another physician's flawed method for death determination. Dr. Middeldorf devised a tool comprised of a 4-inch needle with a flag on the end that would be plunged into the heart of the patient. Middeldorf suggested that a still-beating heart would cause the needle to move and the flag would wave, indication life. However, this test had only one certain outcome – death. Finally, Dr. Brouardel summarized that the only true way to know an individual is dead is to allow them to begin to decompose, stating, "When we meet with putrefaction, there can no longer be any doubt at all as to the reality of death" (35).

Aside from the questionable methods and instruments of these early efforts toward death investigation innovation, scientific progress was being consistently made in the 12th century and onward. However, the "Dark Ages" of the 10th and 11th centuries proved to be a difficult time for the advancement of the forensic sciences as scientific advances and intellectualism in general experienced a marked decline. In 925 A.D., the Office of the Crowner was established by *The Chart of Privileges,* leading to what would eventually become known as the Office of the Coroner. The Office of the Crowner was, by design, formed to protect the financial interest of the Crown. This is in stark contrast to the way that death investigations are conducted today wherein they provide a thorough investigation into an individual's cause of death. Rather, these "crowners" held various juridical positions which ranged from tax collection to inquests into the deaths of individuals who died as a result of so-called "misadventure" known today as suspicious or unexplained circumstances. They were also given the power to collect evidence as part of their investigation which often included animals and property. These crowners, though responsible for conducting investigations, were not the ones who issued a verdict in a death investigation. They were tasked with finding a group of "good men" who would vote on a verdict establishing manner of death, with the crowner's evidence and investigation playing the major role in their decision. Certain manners of death, including suicide, became a common-law crime that resulted in tax penalties. Often, a decision regarding manner of death of was made based on the circumstances surrounding the death without an examination of the body, which led to rampant corruption. Since there were tax penalties associated with certain manners of death such as suicide, it became a common practice to bribe a crowner to define the cause or manner of death as one that would benefit the families and prevent the seizure of property of money in the process of an inquest. This was problematic, though, because the crowners were not medical doctors and often had little to no medical training or knowledge, which further compromised the integrity of the early death investigation processes. Only those who could afford to place a bribe would be able to influence the determination of cause or manner of death of their family member; those in lower socio-economic statuses would be unable to afford the crowner's "fee" and may, as a result, be subject to property or money seizure if the death was certified as one that mandated tax penalties. It wasn't until 1533 that this practice was put in check through the establishment of *The Carolingian Code* which stated that in the course of a death investigation or inquest, the wounds should be opened and examined, particularly in cases with suspicious circumstances surrounding the death (36).

Moving from Europe to America, death investigations continued to improve, and offices of the coroner were officially established, written records of autopsies were kept, and educational requirements were put in place for those physicians conducting autopsies (i.e., the establishment of the medical examiner system that requires an M.D. to perform an autopsy). However, even the establishment of these offices did not entirely eliminate corruption within the context of a death investigation. One such example is a case study from Boston, MA in the early 1880s. During this time, the city of Boston itself was divided into multiple districts with a Coroner in each district. One morning a baby was found dead in a trash can. The Coroner of that district summoned a jury of his choosing – much like what was done in Europe prior to the establishment of the Carolingian Code – and returned a verdict of "death at the hands of a person unknown." For their services, the Coroner was paid $10 and each juror was paid $2 – a hefty sum of money for the time. Rather than continuing to investigate the circumstances surrounding the baby's death, the financial opportunity of the situation was realized and taken advantage of by the people in judicial and investigative power. The baby was placed in trash cans of adjoining districts for the same "investigation" to take place, yielding the same results, which allowed people to continue to get paid and capitalize on the death of a child – a process that was repeated four additional times with the same set of remains. Even more egregious was another contemporaneous case in Brooklyn, NY where a dismembered leg was found in an ash barrel. The fees for a coroner's inquest had recently been increased, so investigations were particularly lucrative. In order to capitalize on the potential financial gain, the leg was further "subdivided" in an effort to increase their financial gains. In this case, the inquest fee was $15, and it was repeated fifty times for a sum total of $750 from one individual's death (37).

Theoretical Application

Unlike many fields of science, the forensic sciences are not one single discrete discipline; they are trans-disciplinary, and it takes the collaboration of multiple specialties to effectively investigate a crime. These collaborations are based on attention to detail, and the culmination of the accumulation of the details – more commonly called evidence in the forensic sciences – leads to successful prosecution of legal cases. Historically, the fundamental purposes of the groups of disciplines we now recognize as the forensic sciences arose from varied motives. Some, such as the homicide investigation in 13th Century China, were genuine in their efforts to bring justice and closure to victims of crimes. Others, in contrast, took advantage of the positions of power provided by death investigation and used it for monetary gain (36). Issues of bias and corruption in the law enforcement communities (among many other disciplines which are also rife with these problems) are complex and widespread, and while they are not directly explored in this dissertation's research, there is an important implication to be discussed.

A great deal of anthropological and ethnographic research has been done throughout the years that explores concepts of structural violence against marginalized people with lower socioeconomic status and the ways in which they are given unequal treatment. In fact, an entire dissertation could be written exploring these factors and the ways in which concrete and quantitative data can be used to combat the inconsistencies, biases, and oversights that may negatively affect or influence investigations. This type of data can provide a distinct perspective within the bounds of ethnographic witnessing of structural violence in that it challenges the political engagement in structural violence by offering a system of checks and balances that can operate independently of the more traditional systems that may be more susceptible to bias or unequal advantages or disadvantages based on status. Although not directly related to the research conducted and data presented in this dissertation, it can be theoretically applied to broader social and cultural contexts, including the work of anthropologists such as Nancy Scheper-Hughes. An anthropological viewpoint provides a unique frame of reference for the application of scientific research such as this dissertation to globally and socially relevant issues such as those explored by anthropologists (38, 39). Stepping back from the microscopic viewpoint of the data itself and, instead, taking a holistic approach to the association of concepts that utilize discrete data for application to larger issues of social justice, it becomes easier to see the necessity of work such as this, particularly with regards to the systematic application of the methodology in an effort to combat bias.

Some of Scheper-Hughes' work explores how people in the slums of Brazil are treated in terms of the investigations surrounding their treatment (i.e., violence against them or death), particularly that their lower socio-economic status and/or gender identities often result in little to no investigation and a much lower emphasis is placed on the significance of the crimes against them, particularly issues of infant mortality. Women in Brazil, for example, may neglect their children – not out of malicious intent – but rather due to acute and extreme poverty which may, in turn, lead to the deaths of those children. In a technical perspective, these deaths would be considered by police investigators to be homicide, or at least manslaughter due to reckless or criminal negligence or neglect. However, they often do not consider the dire circumstances surrounding those deaths and the inescapable cycles of poverty and structural violence that are perpetuated in those parts of society, the people who are exposed to and suffer from what Scheper-Hughes terms "invisible and sacrificial violence" (38, 39).

In these marginalized communities, there may be limited access to the traditional means of postmortem identification such as fingerprints, dental records, or DNA. It is estimated that only 20% of the American population has fingerprints on record for comparison, so it is certainly reasonable to presume that the majority of individuals living in Brazilians slums also do not have fingerprints on record. They likely also never went to a dentist for x-rays that could potentially be utilized for comparison to deceased remains. DNA, while the most feasible option in these types of cases, is often expensive and time consuming which precludes most agencies in these areas from utilizing it in investigations they deem non-crucial. Thus, this dissertation research (or future extensions of it) could be useful in linking bodies together based on various stages of decomposition.

While it would only be a stepping stone in a preliminary investigation, research of this nature can have a cross-cultural application and would not necessarily require a certain financial or social status to implement the methods. Science in general, thus also experiments grounded in the scientific method, seeks to create a model of the working of the world free from a cultural bias. However, when applied to death investigation, these scientific studies cannot and should not be free from culture and still be successful in their application to investigations. In order to understand how humans and their decomposing bodies are incorporated into the world as a whole, one must also understand the overarching socio-cultural applications and implications of the methodological mechanisms behind death investigation research. That is, an investigator must undertake a victim-centered approach to a death investigation which requires a pointed balance between the physical body of the individual and a socio-cultural understanding of the importance and value of the surrounding environment to draw relationships and conclusions associated with the context of the remains. Further, this could be used to describe how police and juridical systems misrepresent marginalized groups of people through differences in the investigations into their deaths (38, 39). In order to make any meaningful extrapolations into racial, gendered, or socio-economic differences in decomposition within the context of human trafficking or human rights violation cases, it is crucial to first have a valid and reliable method from which to establish a baseline for comparison.

Looking at broader anthropological and theoretical applications, Michel Foucault presents arguments that the shift in repercussions for criminal activity from bodily punishments such as torture to non-corporeal punishments of imprisonment were not due to enlightenment, but rather because the codes of justice are a means to enact social power. Corporeal punishments to the actual body of an individual were associated with the time when crimes were seen as an affront to nobility. Over time, this changed to a depersonalized penal system with the shift away from viscerally brutal punishments to the methods of imprisonment that served to dehumanize the prisoner. Historically, society was ruled by nobility and royalty; affluence played a great role in the ability to influence the law in one's favor. This demonstrates, on a fundamental level, the need for standardization of methods for criminal prosecution in an effort to eliminate the sociocultural biases that may affect the proceedings of such investigations (36). As time passed, the control of society began to shift toward the middle class, which in turn affected a change in the creation and application of laws and the judicial systems. This has, over time, changed the understanding of "justice" and led to a more fluid application of the concept (40). It is for this reason that victim identification is so crucial to a death investigation. The necessity may seem obvious – one must identify the deceased in order to prosecute a crime that has occurred – but the practice and application of victimology is much more nuanced. It is essential to study not only the bodies of the victims (though this is an essential starting point represented by micro-level studies such as this dissertation research) but also who the victims were in life in order to understand how their identities may have influenced the crime committed against them. One must understand who the victim was in life to fully grasp the implications of how they died as these two concepts are often connected (41).

The concept of the dead being voiceless may seem self-evident, but when viewed through the anthropological lens of the study of decomposition processes as a form of ethnographic witnessing for those who cannot speak for themselves it becomes much more significant. It calls into question what voicelessness really means. Quantitative scientific studies such as those presented in this dissertation provide the foundational framework for broader applications; they are a first step toward extensions of research that may be global in scope. Methodologically, data and research should be absent of bias. Quantitative scientific research and the methods generated from such experimentation should be equally available to everyone for appropriate application regardless of socioeconomic status, gender, or any other bias-influencing factors. By extension, this includes equal availability of the methods used in a death investigation – such as those for postmortem interval estimation – to both the defense and the prosecution in a criminal case. This is exemplified in the adversarial court system of the United States wherein it is the right of all defendants to hire their own experts to independently evaluate the validity of the evidence being brought against them. This, in turn, supports the fundamental premise of the American judicial system that all those accused of a crime are innocent until proven guilty and are entitled to a trial with a jury of their peers.

Contextual Application

Therein lies the importance of the work of forensic death investigators. These individuals see death every day, making their careers out of closely inspecting the dead, picking up the puzzle pieces and putting them together to create a clear picture of the events surrounding the death event they are investigating. Individuals outside of this career field then have to put their trust in the investigators to bring justice to the deceased and closure to the surviving families and friends. Though they are unrelated to the deceased, investigators hold the power within this security framework as they are the only ones involved who possess the knowledge necessary to figure out the integral aspects of a death investigation – cause and manner of death and, ever important, time since death.

This dissertation research focuses on the minute scale of how organisms decompose, using pigs as a proxy for humans (16). As such, issues of taphonomy are necessary to include and understand to determine the relationship of the environment in death determination of humans and other specimens. While the methodology is specifically aimed toward estimation of the postmortem interval using total body score and accumulated degree days, the overarching goal is to use this as a step toward a more effective way to aid in death investigations. It is a method that allows a traditionally qualitative observational process to be quantified, which provides value in a court of law. Methods of death determination have changed dramatically throughout the centuries, and although it is a question that is asked in nearly every death investigation, it is one that is often answered with a low degree of accuracy or certainty.

Although methods of determining whether an individual is alive or dead have been investigated for centuries, modern technology has made death determination much easier, though there is still uncertainty regarding complete death (i.e., clinical vs. brain death). Many pages could be written and argued about when a person is truly “dead” – is it their body or their mind that fully symbolizes and represents their living being? As such, it has become of greater interest to investigators, scientists, and doctors to instead turn focus to determining the time of death for those individuals who are certainly deceased. With death being an inevitability of life, it may seem obvious why any individual would be interested in determining time of death, circumstances of death, or any such issue. However, this issue is more complex than it may seem on the surface. In particular, every case of death investigation is different, just as every individual is different. It is these differences in the victims themselves – and the victimology associated with each case – that makes the task at hand uniquely difficult. Using the environment’s relationship to the body in a decomposition situation, commonly and simply defined as forensic taphonomy, is an excellent tool for a forensic investigator (42).

In Florida, the Office of the Medical Examiner is tasked with examining specific circumstances involving the death of a human including criminal violence, accident, suicide, suddenly (when in apparent good health), in prison or police custody, or in suspicious or unusual circumstances and because the manner of death may not be immediately apparent on scene (or may be misleading) every scene must be analyzed without bias or predisposition. Applying the same basic methodologies to every crime scene or death investigation can allow for a better understanding of the uniqueness present within each scene. It is this uniqueness that mirrors the identities of the victims themselves which can provide a balance between potentially conflicting ideas and entities involved in an investigation. This may, in turn, have further implications toward larger issues of social justice and equality and may act as a counter-balance against bias on scene, such as presumptions of innocence or guilt. There is no single methodology that can be used in isolation to solve a death investigation, this dissertation research included. It is the combination of appropriate application of numerous methodologies that have built on each other throughout decades of research and the unbiased communication across involved investigators, scientists, and researchers that leads to a successful death investigation, bringing justice to the victim and giving a voice to the voiceless.

Starting with the most simple, foundational level (i.e., empirical research) and expanding toward larger-scale sociocultural or socioeconomic issues to which the pure science of research can be applied demonstrates the necessity of new studies that continually seek to better the methodologies used for application to a myriad of cases and circumstances. The forensic sciences are process driven disciplines which seek to explain complex questions of motive or intent through the use of evidence to support claims and assertions of either guilt or innocence. However, even though the methods for evidence documentation, collection, and analysis are created and implemented with the ultimate goal of standardization the concept of inherent bias cannot be overlooked. Even if an investigator is able to consistently perform his or her job duties in the absence of bias – a skill which most forensic scientists strive to achieve – there are other significant issues of bias and misrepresentation that are often not considered within a death investigation. One such issue has been dubbed "missing white woman syndrome" which is the phenomenon where missing persons reports of white females are given a great deal more media coverage and attention than any other demographic group. Even the nature of the media coverage received varied based on demographics such as age and race, including the framing of the notion of the victims' potential participation or involvement in the event(s) leading to their disappearance (49). Methodologies that assess the total number of missing persons reports in a given area over a given period of time and cross-reference them with news stories and/or articles associated with the reports are designed to draw a correlation between demographics and media coverage. However, even though these studies may seem empirical in nature, the methodologies are still rife with flaws that could lead to biased interpretation of the results. Incorrect or inaccurate interpretation of the missing person by investigators, news media, or even the family/friends filing the report could lead to systematic misrepresentation of their information in the media. That is, they may be classified or represented as one demographic group when, in reality, they were self-identified as members of another. Further, issues of physical attractiveness have also been documented to play a role in the media coverage that a missing person's report receives with the concept of attractiveness, of course, being a very subjective notion. (43, 44, 45)

This is just one example of innumerable others that highlight the importance of not only a standardized methodology but also a standardized application of that methodology to combat bias and variables in assessment that are otherwise difficult to control. The standardization of the methodologies used in investigative efforts is an important first step, but the overarching goal is the universal and standardized application of these methodologies to all cases that involve a decomposing body. When purely qualitative methods are used as the basis for assessment, many outside factors can affect that assessment which can lead to inconsistencies in the evaluation of remains. This can, in turn, negatively affect the investigation. These outside factors, perspectives, and conditions that may affect an investigators ability to offer a truly unbiased opinion are difficult to control with qualitative assessments. However, when a quantitative method is put into place instead, it takes a major step forward toward standardizing the investigative techniques of decomposed remains. It is, thus, the standard application of the standard methodology that would hold the most weight and offer the most significant improvements in death investigations.

Qualitative methods such as those that have traditionally been used as the primary way to estimate time since death based on degree of decomposition lend themselves to far greater inaccuracies than the quantitative methods that are proposed in this dissertation. Take, for example, an investigator who is wholly unfamiliar with decomposition who is, then, tasked with developing an estimation of the postmortem interval for a decedent under their investigatory jurisdiction. Their overall unfamiliarity with the processes of decomposition may lead them to overestimate the postmortem interval as they are unfamiliar with the nuances involved in the decomposition processes. Likewise, a well-seasoned investigator who has seen a great deal of decomposition may be more inclined to underestimate the PMI due to a propensity toward estimating the minimum postmortem interval, rather than running the risk of overestimation. While this is only one simple scenario, it illustrates the necessity of more standardized methods for data collection on scene that can then be used for postmortem interval estimation in a decomposition case. Offering quantitative methods that take steps to reduce the observational and investigatory bias present in investigations – whatever the reason or source behind the bias may be – leads to a more accurate and ultimately fruitful investigation that has implications far beyond the direct application to forensic death investigation.

CHAPTER 2
MATERIALS AND METHODS

Definition of Terms

There are numerous terms used within this dissertation that have unique applications and definitions in the forensic sciences. Members of the forensic science community should be familiar with these terms, but for ease of understanding to a reader outside the forensic sciences and for overall general clarification, several key terms are defined below with definitions that should be applied throughout this dissertation.

- ACCUMULATED DEGREE DAYS. A standardized measurement of thermal units that are measured across 24-hour periods of time; generally associated with the growth and development of arthropods.
- ANIMAL SCAVENGING. A phenomenon associated with tissue loss and disarticulation of decomposing remains as a result of the carnivorous behavior of animals which view the remains as a food source (e.g., vultures, coyotes, etc.) (Figure B-1).
- BLOATING. The distention/inflation of the abdomen as a result of putrefaction due to anaerobic bacteria breaking down tissues and organs during early decomposition (Figure B-2).
- MARBLING. The phenomenon of subdermal vessels (i.e., veins) becoming more readily visible through skin; veins often appear darker against lighter decomposing tissue and produce a “marbled” appearance (Figure B-3).
- MOIST DECOMPOSITION. A process of decomposition as a result of the self-dissolution of tissues and internal breakdown of organs due to bacterial and protein degradation resulting in decomposition fluids; often associated with insect colonization (Figure B-4).
- MUMMIFICATION. A state of decomposition as a result of an arid climate (often extremely hot) resulting in a dry and leathery skin condition that inhibits moist decomposition; causes dehydration of organs and tissues resulting in drying and shriveling of body (Figure B-5).
- POSTMORTEM INTERVAL (PMI). Time since death.

- PURGING. The escape of fluids from the mouth and nose as a result of early decomposition; not to be confused with blood loss due to trauma in the head/neck region which may be observed in an earlier state of decay than purge fluids (Figure B-6).

- SAPONIFICATION. A state of decomposition as a result of hydrolysis of fat tissues into oleic, palmitic, and stearic acids forming a grayish waxy substance during the decomposition process of soft tissue subjected to moisture; requires a moist, anaerobic environment.

- SKIN SLIPPAGE. The sloughing off of the epidermal layer of tissue as a result of early decomposition; often associated with the tissues of the hands and feed (Figure B-7).

- TOTAL BODY SCORE (TBS). A quantitative method of grading decomposition based on independent numerical assessment of the degree of decomposition in the head, torso, and limbs/extremities.

Delimitations, Limitations, and Assumptions

Delimitations

This study was conducted with the following parameters:

- All trials were at the University of Florida's Austin Cary Forest.

- Each trial consisted of 10 individual independently monitored specimens.

- The pilot trial utilized pit-bull mix dogs *(Canis familiaris)*.

- All subsequent trials utilized pigs *(Sus scrofa)*.

- All specimens were obtained as carcasses. The researcher was not involved in the euthanasia in any way.

- The time of death for each specimen was and documented within a one-hour approximation.

- Each specimen was on the soil surface (i.e., not buried or otherwise covered with soil, leaf litter, or other materials) and covered with a cage constructed of chicken wire and wooden boards. The purpose of the cage was to prevent animal scavengers from eating and/or removing the remains throughout the duration of the trial.

- Temperature probes were placed with each specimen to monitor the ambient temperature approximately 4 feet above the remains.

- Hourly temperature readings of each probe were collected and utilized to determine daily high and low ambient temperatures above each specimen which was compared to the certified weather data collected at the Gainesville Regional Airport.

- Daily photographs were taken of each specimen throughout the course of the trial. These photographs documented overall condition of the remains as well as state of decomposition of the head, torso, and limbs. Any unique artifacts of decomposition that can be utilized to determine TBS were also photographed.

- The temperature data collected each day was utilized to calculate accumulated degree days for each specimen.

- The ADD data was associated with TBS. This allowed the researcher to determine how long it took in thermal units, rather than calendar days, for each individual TBS to be reached.

Limitations

In designing this study, the researcher recognized that the following limitations exist within the confines of the research project:

- The placement of specimens underneath cages prevented the interaction of animal scavengers with the remains. In a real-world scenario, animal scavenging is common and can affect (i.e., speed up) the decomposition process either through additional tissue loss due to feeding or through complete removal of portions (i.e., disarticulation) of the remains. However, for the purposes of this study, every effort was undertaken to prevent animal scavenging as the risk of complete loss of specimens as a result of scavenging was deemed too great.

- The researcher recognized the possibility that daily intervention in the remains (i.e., removal of cages for photography and TBS assessment) may have affected the decomposition process, with particular regards to insect colonization. Every effort was made to minimize changes as a result of human intervention – particularly through minimal handling of the remains – but the extent to which daily observation affected the rate of decomposition is not known at this time. To minimize the potential effects of human intervention, on days when no TBS is observed, the cages were left in place and a single photograph of the remains through the cage was taken.

Assumptions

In designing this study, the researcher made and operated within the following assumptions for research purposes:

- The decomposition process of specimens in the study was not affected by animal scavengers. This was ensured by the use of cages, stakes, and bungee cords to prevent scavengers from accessing the remains. The effects of animal scavenging on the decomposition process were not explored in this study.
- The cages did not affect the decomposition process. As insects were still readily able to access the remains, airflow was not obscured, and the specimens contained within the cages still received full sun, it was not expected or observed that the cages changed the rate of decomposition in a meaningful way. Though the statistical significance of this change was not explored in this study, previous experience by the researcher in both workshops and casework was utilized to make this assumption.
- The specimens were handled or moved throughout the course of the research. This was intended to mimic the natural process of body deposition such as in a homicide investigation where a body is deposited in an outdoor environment and left undisturbed (including by scavengers) until discovery and investigation.

Pilot Study

The first replicate trial in the study utilized 10 pit-bull mix dogs. These dogs were obtained from the Lake City Humane Society. Their approximate weights were 60-80 lbs. each. The dogs utilized were scheduled for chemical euthanasia and were diverted to the research trial rather than cremation. The exact weight of each dog and the time of death were documented. Upon picking up the dogs, each was photographed and assigned a number associated with their cage and temperature probe. The specimens were transported to the University of Florida's Austin Cary Forest where they were placed individually on the soil surface. In an attempt to fully separate the specimens, they were scattered throughout a half acre area with 5 of the specimens being placed in full sun and 5 in full shade (i.e., under thick tree canopies). (Figure B-8) Cages constructed of wooden 2x4s and chicken wire was placed over each specimen and staked down into the ground with wooden stakes and rubber bungee cords. The purpose of the cages is to prevent animal scavengers from accessing the specimens and feeding on the remains, disarticulating them, or removing them entirely. Each cage also had a wooden arm that extended 4 feet over the remains to which a time lapse camera and a temperature probe were attached. (Figure B-9) The temperature probe recorded ambient temperature over each specimen as well as the temperature from an extended probe at the body-soil interface. The time lapse cameras took one picture each day at 7pm to document the progression of decomposition. Upon completion of the trial (i.e., complete skeletonization of the remains) the equipment and bones from each specimen were collected. The skeletons of each dog were kept for use as teaching aids in the UF-ASPCA Veterinary Forensic Sciences Program due to the unique taphonomy that was present on the bones. It became evident that higher quality photos would be necessary to fully document the stage of decomposition each day as the time lapse cameras did not capture enough detail to make minute determinations of total body score. As a result, future trials would require daily trips to the research site for the researcher to take more detailed photographs. Data from this pilot study were not used except to better hone the methodology used in future trials.

Methodology

The second replicate trial in the study utilized 10 pigs obtained from the North Florida Livestock Market. Their approximate weights were 70-130 lbs. each. The pigs were intended for use as a food product but were diverted to research instead of a butcher. The exact weight of each pig and the time of death were documented as a starting point to assess postmortem interval. The pigs were already bagged upon pickup at the livestock market, thus they were transported directly to the Austin Cary Forest and photographed on site prior to placement in cages and being assigned a number. In addition to the change in photographic documentation methods, it also became evident that the variation in placement of the specimens was too difficult to control. Therefore, the pigs for the second and all subsequent trials were placed in staggered rows along a semi-cleared firebreak. (Figure B-10) This was to minimize changes due to environmental placement since each specimen would receive some sun and some shade throughout the day. The same cages were utilized for the pigs as the dogs. Temperature probes and time lapse cameras were again placed onto the mounting bracket above the cages for hourly temperature collection as well as a daily high and low ambient temperature. The pigs were photographed in situ on day one of the trial. Daily trips were made to the forest wherein each pig was photographed at least six times: one overall photograph with the cage over the pig and a photo board documenting date and time, an overall photograph of the whole pig after cage removal, photographs of the head, torso, and limbs, and another overall photograph prior to placing the cage back on each pig. (Figure B-11). Taking an additional overall photo after close-up photographs each day may seem redundant, but the purpose of this photograph was to prove that no changes or alterations were made to the specimen in the process of collecting daily decomposition data and/or photographing the specimens. This is similar to the concepts utilized in crime scene photography where an investigator takes overall photographs after initial arrival on scene and then takes another set of overall photographs after the investigation is complete before the scene is released to document any changes that were made in the investigation, including any items of evidence that may have been collected.

As decomposition progressed, particularly bloating of the remains, sometimes the upper and lower limbs had to be photographed separately. If any unique artifacts of decomposition were present that may aid in assessment of total body score (e.g., marbling, skin slippage, etc.) these were also documented with close-up photographs. Pigs nine and ten were initially too bloated to safely remove the cages without risking damage to the remains, so they were photographed in the same way through the cages each day. Each day the pigs were assessed for a TBS determination which was documented in a spreadsheet. The TBS determination was made using a chart that was a modified compilation of all other previously published methods for determining TBS, broken down into stages of fresh, early decomposition, advanced decomposition, and skeletonization (1). (Figures 2-12, 2-13)

Due to the cold weather and intermittent rain, the pigs began to mummify on top and saponify on bottom which dramatically slowed down their rate of decomposition. (Figure B-14) After several weeks of very minor TBS changes, it was determined by the researcher that trips every other day to the forest (i.e., Monday, Wednesday, and Friday) would be sufficient for TBS assessment and photographic documentation rather than daily trips. This proved adequate for the remainder of the trial. Due to the states of mummification and saponification of all pigs in this trial, the researcher elected to terminate the trial once all specimens reached a TBS of 27 or higher – indicating that they had reached complete bone exposure under mummified tissue. It would have taken many more months for all specimens to completely skeletonize and reach the final TBS of 35, if at all.

After completion of one replicate with dogs and one replicate with pigs, it was evident that some modifications to the methodology were necessary. Initially in the pilot study, daily monitoring of the research site was done using time lapse cameras mounted to overhead brackets over the cages. While this proved useful in that the cameras took photos from exactly the same location at the same time each day, the quality of photos was not detailed enough to differentiate minute differences in decompositional changes. Daily monitoring in person was necessary so that more detailed overall photos as well as close-ups of any noticeable changes in the state of decomposition can be taken. During the pig trials, daily trips to the research site were made which allowed for a higher quality of documentation. Each day the pigs were photographed in their overall state and close-up photographs of the head, torso, and limbs (either upper and lower included in one photograph or upper and lower photographed separately, depending on orientation of the limbs and artifacts of decomposition to document) were taken. After these four or five photographs, any other unique artifacts of decomposition that would aid in the assessment of total body score that day (e.g., marbling, skin slippage, bone exposure, etc.) were photographed. A final overall photograph was then taken before placing the cage back over the pig to indicate that the pig was not altered in any way during the process of photographing each anatomical region.

For all pig trials, once each trial had been terminated the remains were collected and bagged for chemical digestion at the University of Florida, with the exception of the specimens in trial 3. These specimens remained at the research site through December 2017 in order to assess additional taphonomic changes to skeletal remains that occur over time. These taphonomic changes are not directly addressed in this research, but rather may provide material for a future publication (21). Each temperature probe collected hourly temperature readings of the ambient temperature four feet above the remains. They also documented daily high and low ambient temperatures which were used for calculating accumulated degree days. The daily ambient temperatures (i.e., average of high and low) were used to calculate ADD which was then associated with TBS. Charts were created which showed the number of ADD it took to reach each TBS measurement. This was done individually for each pig specimen as well as the overall average of all 10 specimens each trial. (Figure B-15) Standard error was calculated to determine the accuracy of the methodology in predicting postmortem interval based on TBS and ADD and expressed by means of standard deviation and the standard error of the mean. (Table A-1) Although all temperature readings from the research site and the certified weather station were initially expressed in degrees Fahrenheit, conversions were made for the data to be expressed in degrees Celsius for the purposes of this dissertation.

CHAPTER 3
RESULTS

Overall

The relationship between TBS and ADD when plotted against one another – TBS as the x-axis and ADD as the y-axis – demonstrate an exponential relationship which is consistent with the results of other similar studies. Unlike other studies, however, this study did not attempt to "straighten the curve" through logarithmic manipulation of the data as did the Megyesi study. The intended purpose of the data produced in this research project is for simple and straightforward use on a death investigation scene by law enforcement officers, crime scene investigators, and/or death investigators. As such, keeping the information in its most basic and organic form that still yields statistically meaningful and reliable results is preferred.

Unlike many previous studies that have addressed similar questions of postmortem interval estimation based on ADD and TBS, this dissertation does not seek to develop a universally applicable equation for use on scene. The results of three complete trials of this research demonstrated a vast difference in the time it took specimens to fully decompose, as well as the nature of progression of decomposition based on environmental and seasonal differences. Trial one took a total of 129 calendar days to reach completion, with a maximum TBS of 29. (Figure B-16) Trial two took a total of 22 calendar days to reach completion, with a maximum TBS of 35. (Figure B-17) Trial three took a total of 56 calendar days to reach completion, with a maximum TBS of 35. (Figure B-18) (Table A-2) It is for this reason that three separate equations are being proposed to address time since death based on degree of decomposition. These equations are the result of the compilation of data from each of the three trials. The first – from trial one – is based on environmental conditions that are initially closer to freezing and gradually increase in temperature, such as is consistent with a transition from winter into spring. The second – from trial two – is based on environmental conditions that are consistently warm, such as is typical of summer, where there was a good deal of precipitation in the early stages of the trial (i.e., more than 4 inches). The third – from trial three – is based on environmental conditions that are also consistently warm but where the conditions are initially dry and extensive precipitation does not occur until later stages of the trial (i.e., after the mid-point in data collection). Trials two and three are representative of a fairly typical Florida summer season where it is hot and rainy, then there is a period of dry heat, respectively. For comparative purposes, trial two took 22 days for specimens to reach a TBS of 35 during which time the nearest certified weather station reported a total of 8.06 inches of rain accumulated. In the first 22 days of trial three, only 0.89 inches of rain accumulated and the maximum observed TBS at that time was 30, with the average of all specimen in trial three being 29 within the same timeframe. (Table A-3)

In some entomological studies, regression analysis is performed to quantify the significance of the difference between site or scene data and the data collected from a certified weather station. While this research project did utilize both types of temperature data, they were assessed independently of each other to demonstrate the differences that occur between data directly associated with the site of decomposition and data from a nearby weather station. Statistically, standard errors were lower for the certified data for all trials as each specimen was associated with the same certified data – that is, the temperature data was not unique to each specimen when the certified data from the airport was used. This led to less variation in the results. However, when looking at the equations generated from both the site temperature data and the certified temperature data, the R^2 values are higher for the equations generated from the site temperature data. (Table A-4) This demonstrates the strength and importance of the relationship between temperature and rate of decomposition. Even minor variations in temperature can produce major changes in the ability to accurately predict postmortem interval based on degree of decomposition. In an ideal situation, when a decomposed body is found and investigators seek to estimate PMI using the methodology contained in this research, they would place a data logger on scene to collect temperature readings for several days from the site where the body was deposited. They would then be able to use this data in comparison with certified temperature readings and generate what is considered “corrected” data – that is, they could calculate the difference between the temperature data collected on scene after the body was found and the temperature data from the certified station. This could then be used to retrospectively generate estimated temperature values that would likely be most consistent with the site of decomposition itself, rather than the certified weather station.

Trial One

Trial one took the longest of the pig trials lasting 129 days to reach a maximum TBS of 29. On day one of trial one, the average ambient temperature was 8.3°C and on the final day the average ambient temperature was 25.8°C. There were minor fluctuations in temperature several times throughout the trial where it would warm up then cool down, but there were not any major prolonged periods of temperature shift (i.e., more than one week in total duration) during trial one. Precipitation totaled 11.89 inches during trial one, with 5.89 inches at the midpoint. The amounts of precipitation were relatively evenly dispersed throughout the duration of the trial. There was a steady increase in TBS throughout the early stages of decomposition, but as the specimens reached the advanced decomposition stages the progress of their decomposition began to stagnate. Cold temperatures (near freezing at times) and rain were deterrents to insect colonization and, as a result of the moist conditions at the body-soil interface, the underside of many specimens began to saponify. The top portions exposed to sun and airflow began to mummify. Once these processes occur, it takes many months of specialized insect activity (e.g., beetle scavenging) to remove mummified tissue. After all specimens reached a minimum TBS of 27 – indicating bone exposure under mummified tissue – the trial was terminated.

Plotting TBS against the ADD calculated from the site temperature data in trial one generated the equation $y = 37.04e^{0.1373x}$ with an $R^2 = 0.8584$. The same process was repeated for the certified temperature data and generated the equation $y = 28.33e^{0.1445x}$ with an $R^2 = 0.8482$. The standard error for the site data was 25.655 ADD and was 23.674 ADD for the certified data. These equations offer a method of calculating the number of ADD it would take to reach a particular TBS in a death investigation, within a range including the standard error. In addition to the overall equations for trial one, the TBS was plotted against the research site and certified ADD for each specimen, generating a total of 20 possible equations unique to each specimen. (Figure B-19) The fit demonstrated by the R^2 values was the lowest for trial one. This is consistent with the fact that as time since death increases, it becomes more difficult to accurately estimate postmortem interval.

Trial Two

Trial two was the shortest of the pig trials lasting 22 days to reach a maximum TBS of 35. On day one of trial two the average ambient temperature was 28.3°C and on the final day the average ambient temperature was 28.8°C. There were very few fluctuations in temperature throughout this trial with the lowest recorded average temperature being 23.6°C and the highest being 29.1°C. Precipitation totaled 8.06 inches during trial two, with 7.09 inches at the midpoint. The amounts of precipitation were heavily concentrated in the first half of the trial which contributed to the rapid rate of moist decomposition. There was a rapid and steady increase in TBS throughout the early and advanced stages of decomposition, but as the specimens began to skeletonize their progression began to slow. Some experienced small amounts of mummification in the latter portion of the trial which is consistent with the warm and dry weather conditions that occurred during the last half of trial two. Not all specimens reached the maximum TBS of 35, but all experienced some degree of skeletonization more than half of the remains – an observed minimum TBS of 29 – at which point the trail was terminated.

Plotting TBS against the ADD calculated from the site temperature data in trial two generated the equation $y = 34.66e^{0.0874x}$ with an $R^2 = 0.9165$. The same process was repeated for the certified temperature data and generated the equation $y = 31.94e^{0.0882x}$ with an $R^2 = 0.9157$. The standard error for the site data was 12.51513 ADD and was 11.7324 ADD for the certified data. These equations offer a method of calculating the number of ADD it would take to reach a particular TBS in a death investigation, within a range including the standard error. In addition to the overall equations for trial two, the TBS was plotted against the research site and certified ADD for each specimen, generating a total of 20 possible equations unique to each specimen. (Figure B-20) The fit demonstrated by the R^2 values was the highest for trial two. This is consistent with the fact that time since death is more accurately predicted with shorter windows of the postmortem interval.

Trial Three

Trial three was the intermediate in length of the pig trials lasting 56 days to reach a maximum TBS of 35. On day one of trial three the average ambient temperature was 29.1°C and on the final day the average ambient temperature was 26.6°C. There were very few fluctuations in temperature throughout this trial with the lowest recorded average temperature being 26.1°C and the highest being 30°C. Precipitation totaled 4.18 inches during trial three, with 0.89 inches at the midpoint. The amounts of precipitation were heavily concentrated in the last half of the trial which contributed to the slower rate of decomposition as the dry conditions cause mummification to begin in some of the tissue. However, once precipitation began to occur, insect colonization increased and moist decomposition continued. There was a steady increase in TBS throughout the early stages of decomposition, but as the specimens reached the advanced and skeletonization stages their progress slowed. This is likely due to the dry conditions that caused mummification in some specimens. Not all specimens reached the maximum TBS of 35, but all experienced some degree of skeletonization more than half of the remains – an observed minimum TBS of 30 – at which point the trial was terminated.

Plotting TBS against the ADD calculated from the site temperature data in trial two generated the equation $y = 18.244e^{0.1265x}$ with an $R^2 = 0.91$. The same process was repeated for the certified temperature data and generated the equation y =

$17.054e^{0.1274x}$ with an $R^2 = 0.9093$. The standard error for the site data was 36.62354 ADD and was 35.31765 ADD for the certified data. These equations offer a method of calculating the number of ADD it would take to reach a particular TBS in a death investigation, within a range including the standard error. In addition to the overall equations for trial three, the TBS was plotted against the research site and certified ADD for each specimen, generating a total of 20 possible equations unique to each specimen. (Figure B-21) The fit demonstrated by the R^2 values was intermediate for trial three between the fits of trials one and three. However, it had the highest standard error of the three trials. This is likely due to the fewer number of collected data points associated with trial three. As it became evident that the specimens were decomposing slowly, trips every other day were substituted for daily trips, and at the very end of the trial trips were only once per week to ensure that decomposition had reached its plateau before termination. Although the postmortem interval for trial three was 43% the length of trial one, it had only 26% the number of collected data points plotted against the total number of ADD calculated. Although the standard error is higher due to the fewer data points, the high R^2 values demonstrate that the equation generated remains a good fit to predict postmortem interval.

Example Calculation

The obvious question at the culmination of any research project such as this is how will it be practically applied in a real-world scenario. Suppose an individual went missing in early summer (e.g., June) and was discovered deceased and decomposed about a month after he or she was last seen alive. The data most closely correlated with the circumstances of this investigation comes from trial two, although trial three may be a contender depending on amounts of precipitation during the supposed time since death. However, in the absence of drought conditions throughout the period of disappearance trial two remains most appropriate for application. When the investigator is on scene a TBS determination must be made by assessing the head, trunk/torso, and limbs/extremities using the TBS chart provided in this dissertation. That would represent the x-value in the calculations. The y-value would then be the estimated ADD which could be solved for by plugging in the known value of TBS. For the trial two data, the equation based on research site data would be $y = 34.66e^{0.0874x}$. Inputting the TBS of 30 determined on scene you would solve for y using a scientific calculator, yielding the result 477.033 ±12.51 ADD. The equation based on certified research data would be $y = 31.94e^{0.0882x}$. Inputting the TBS of 30 determined on scene would yield the result 450.275 ±11.73 ADD. The investigator would need to obtain the certified temperature data from the weather station nearest the crime scene for no less than the period of time the decedent was last seen alive until the date of discover. The investigator would work backward adding up the daily average ambient temperatures from the date the decedent was discovered until the sum total reached the numbers generated by the equations. In this case, using both equations to give a maximum and minimum estimation for ADD, the investigator would be looking for the total between 438.545 and 489.543 ADD. Using the certified data from trial two in this dissertation research project, the estimated time since death for that range would be between 17-20 days. To compare for accuracy, two of the specimens had a TBS of 30 on day 17, four had a TBS less than 30, and four had a TBS more than 30. On day 20, three of the specimens had a TBS of 30, three had a TBS less than thirty, and four had a TBS more than 30. This demonstrates that the methodology developed in this research project provides a good estimate for postmortem interval based on degree of decomposition as assessed by total body score and accumulated degree days.

CHAPTER 4
DISCUSSION

Significance

The search for a universally applicable method to accurately determine postmortem interval or time since death is a topic that has been the subject of numerous research projects across many decades in the forensic sciences. Despite extensive research – both in the field and through retrospective casework analysis – the concept remains elusive to scientists and death investigators. While it may seem an obvious oversimplification, every death investigation case is vastly different in the variables that affect the investigative process. Even cases that may, at first glance, appear quite similar, might in reality require the application of completely different methodologies for postmortem interval estimation. Most new studies – including this dissertation research – are valuable in that they generally each address a specific variable or set of variables (e.g., geographic region, temperature differences, body size, clothing, animal scavengers etc.) very few or sometimes none of these variables are mutually exclusive when applied to a real-world death investigation (3, 4, 5, 7, 8, 9, 11, 12). This is particularly complicated in decomposition cases, because the ability to accurately and precisely estimate the postmortem interval decreases as time since death increases (13).

When approaching a death investigation of a decomposing body, the first question to likely be asked by investigators – other than the identity of the individual – would be time since death. There are numerous methods that can theoretically be applied to a death investigation to help determine postmortem interval, but not all methods are equally applicable. Generally speaking, these methods are either applied to early or late stages of decomposition. Thus, methods such as assessment of livor mortis, rigor mortis, or algor mortis would not be useful in a decomposition scenario. Other methods such as changes in the chemical composition of bodily fluids could be assessed including the potassium levels of the vitreous humor. A problem with this method is that potassium levels increase with time since death and are considered to be highly variable. Within the first 24 hours postmortem the confidence interval would be ± 12 hours, which may still be useful in early stages of decomposition. However, as the postmortem interval increases, so does the standard error associated with potassium levels. For example, they are considered to vary ± 40 hours at 100 hours postmortem, which can alter the time since death estimation by nearly two days thereby making this in inefficient method for use in decomposition cases. Furthermore, studies show that temperature and humidity have no significant effect on the levels of potassium in the vitreous humor, whereas these factors play a significant role in the overall process of decomposition, particularly when attempts to assess postmortem interval are to be made from the degree of decomposition as it is associated with accumulated degree days.

The importance of postmortem interval estimation in any death investigation cannot be overstated. Whether a current case of suspicious death that could be linked to a homicide or a historic discovery of remains where dating can be utilized to associate the individual with other artifacts, time since death is always an integral question. Many methods can be employed to answer this question ranging from changes in the electrolyte concentrations in vitreous humor for very recent deaths to carbon dating for ancient remains, but great difficulty lies in estimating the postmortem interval for remains older than 72 hours that still retain tissue. Generally speaking, forensic entomology can be used in such cases where blow fly larvae are collected and aged to determine a time since colonization which can be used to extrapolate a time since death, but many external factors can affect this estimation. In cases where insects are not present, the only remaining method to estimate PMI is a qualitative assessment of the degree of decomposition of the body. These five stages – fresh, bloat, active decay, advanced decay, and skeletonization – are rife with variation that makes determining an exact time of death extremely difficult (1). Despite this difficulty, it is paramount that an accurate PMI is established, particularly in a homicide investigation, to aid investigators in establishing the identity of the victim and an alibi of the suspect.

A great deal of research has been undertaken to better estimate the postmortem interval and has been accomplished with varying degrees of success. Many of these studies address very specific variables or methods which cannot be universally applied to cases where decomposition has progressed making traditional PMI estimation methods difficult to utilize. As a result, this study should have widespread utility. By utilizing the traditional qualitative aspects of decomposition (i.e., the way the body looks on scene) and associating it with more scientifically quantifiable data (i.e., accumulated degree days) the investigator will have a much more useful idea of time since death. One aspect of data collection can easily be conducted on scene by an investigator who is relatively untrained on this particular methodology, but does possess a knowledge and understanding of the qualitative processes of decomposition and can identify relevant artifacts of decomposition. This information can then be utilized to yield a total body score which can be turned over to an expert in the methodology who can collect local ambient weather data, determine the accumulated degree days it would have taken to reach the TBS determined on scene, and give an estimated time since death that can be quantitatively assessed in a court of law. By utilizing both qualitative and quantitative methods of stage of decomposition, a much more accurate estimate of postmortem interval can be produced.

Overall, this study has the potential to change the way that postmortem interval estimation is conducted in cases where human remains are left to decompose on the surface in an outdoor environment. It has components that are simple enough to be distributed to any death investigator or law enforcement officer for basic use on scene, the information from which can then be utilized to calculate accumulated degree days from local temperature data and produce a useful and accurate postmortem interval estimation.

This is particularly important in the face of cases that are generally lacking in evidence, such as is often the case in death investigations involving decomposed remains that are not otherwise associated with identifiable items of forensic evidence (e.g., remains found in isolation in an outdoor environment). Although there may be missing persons reports with which to cross reference the discovery of a body in a given area, without reliable knowledge of the time since death it would be difficult to conduct a fruitful investigation as even the identity of the victim may be difficult to establish. If an estimation of postmortem interval is established, it may then be useful to narrow down the identity of the victim from the list of potential missing persons generated in the reports. However, a significant limitation to this type of assessment is the inconsistencies in missing persons reports. These inconsistencies range from the most significant in that many individuals who do end up deceased are never reported missing to more minor issues of incorrect details and/or information in the report – though any inconsistencies in the reports can cause significant investigatory issues. (46)

Difficulties in postmortem interval estimation further complicate this issue as a delay in reporting an individual missing, even by only a few days, can cause major hindrances to the investigation. If a decomposed body is discovered and reliable methodologies such as those explored in this dissertation are utilized to develop a postmortem interval estimation it should, in theory, aid investigators in their ability to investigate and eventually solve the case. However, if the information in the missing persons reports given to investigators is incorrect, the accuracy or validity of the postmortem interval estimation would not be as significant. If the PMI estimation suggests the victim has been deceased for two months but the most recent missing person report was filed only a week ago, investigators may not immediately draw a correlation between the two cases which could lead to a stagnation in the investigation. The ability of investigators to understand that missing persons reports may not always be accurate is an important distinction when using said reports in conjunction with postmortem interval estimations in decomposition cases.

Issues of social justice often come into play with regards to missing persons reports, namely in that not all members of society are equally reported missing nor are they given equal media attention if a report is generated. A phenomenon known as “missing white woman syndrome” is one such example in that Caucasian females who have been reported missing are much more likely to receive widespread media attention than other demographic categories. They are also more likely to receive positive phrasing in the articles and headlines and are less likely to be framed as a cautionary tale or otherwise implicated as partially responsible for their abduction. (44, 45, 47, 48) Further, there is a well-documented disparity in whether an individual who has gone missing is reported in the news media at all in addition to disparities in the depth of coverage a missing person receives based on their demographic category (43). It has been suggested that more than 75% of news articles regarding missing persons report on white victims to the exclusion of all others (49).

The complex difficulties of reporting bias and the associated investigatory bias in missing persons reports are not directly within the bounds of this dissertation research, though an obvious correlation can be drawn regarding the significance of the application of the methods of postmortem interval estimation for decomposition cases explored in this dissertation to cases where bias – either inherent or tangential – is present within the investigation. Initially when a decomposed body is discovered very little is likely known about the victim, including identity and demographic information. By approaching the investigation through the use of quantitative methods of assessment such as those presented in this dissertation rather than qualitative methods which are more subject to bias, the integrity of the investigation is better preserved.

For the average individual outside the forensic sciences, this study possesses importance as well. Though many individuals try to avoid thinking about or dwelling on their inevitable demise, it is difficult to entirely avoid. With the sensationalism of high profile homicide cases on major news outlets, even those who have been fortunate enough to avoid direct relation to a violent death are faced with it from time to time.

Even in the back of their minds, people must trust that those whose job it is to investigate these deaths have access to the information and methods necessary to properly and effectively determine cause, manner, and time of death. When uncertainty arises in an investigation in any area (e.g., the alibi of a suspect) the burden falls to the investigators to provide factual information to properly refute it (e.g., time of death). Having a more effective method to determine time of death in a decomposition case – the most difficult ones to determine – will allow for greater faith and security in the ability of investigators to do their jobs, which will in turn allow everyday individuals to go through their lives trusting that should the unthinkable happen, justice would prevail.

As evidenced in the historical development of methods of death determination, without precision and accuracy of measurement, interpretation holds little to no validity or meaning. Poor information within the scientific methodological basis for examination ultimately leads to poor interpretation and application. In this case, pigs are merely a proxy for human decomposition and the study itself is merely a vehicle through which specific decomposition research can be applied to a myriad of more universally applicable cases. Just as an appropriate use of techniques of forensic taphonomy requires the detailed study and examination of both the body and the surrounding environment to understand the circumstances surrounding the death event, in order to understand the broader implications of a study of this nature one must address the individuals being examined. It is imperative to fully understand who the victim was, their unique and individual microhistories that made up who they were in life in order to fully understand the significance and meaning behind their death. Without these tools – the victimology and applications of concepts of ethnoecology to understand the placement of the individual within the environment of death – ultimately this research would have no greater meaning without its application to the world around us.

Future Research Considerations and Study Limitations

Although the field research portion of this dissertation is one of the most extensive that has been undertaken to date, the researcher recognizes there remain some limitations in this study that could be improved by future research. Primarily, a major limitation of this study is the absence of a "fall/autumn" trial that would have assessed decomposition in temperature conditions that started hot and gradually became cold such as is consistent with the transition from fall to winter. Due to time and financial constraints, a fourth replicate trial was not feasible in this study, but the researcher recognizes the importance of this data and intends to continue this research in the future to develop a fourth equation that would address decomposition in such seasonal conditions. Given that Florida remains hot for a large portion of the year, the equations from trials two and three may remain appropriate for application in certain circumstances when the weather remained hot. However, care must be taken when applying the equations outside of the appropriate season of association.

The limitation of appropriate temperature applications must also be given consideration when applying this research to cases where a body has decomposed in a temperature controlled environment such as inside a residence. A fundamental portion of this research methodology is based on the concept of accumulated degree days, which utilize average ambient temperatures. However, in indoor environments with controlled temperatures the ambient temperature remains stable throughout the day, perhaps with only minor variations due to external factors such as airflow from a fan or sunlight shining in through a window. This is different than the environmental conditions at the research site which experienced fluctuations in temperature throughout the day and throughout the trial in general. Likely, a more stable temperature environment would lead to better results with less variation as it is a more controlled variable, but the extent to which this would affect the equations produced has not been explored.

Furthermore, this study was conducted with the intentional exclusion of interference from animal scavengers. However, scavenging is an important part of the decomposition process in an actual death investigation case (28). It was the experience of the researcher from involvement in previous projects and teaching endeavors at the research location that wildlife (e.g., bears) were likely to remove and/or eat the research specimens. The risk of specimen loss was too great a risk for this particular research project. In the future, it would be excellent to allow some scavengers to access the remains, but in a controlled environment. This may be achieved by placing a fence around a large portion of the research site (e.g., five acres) which would allow some wildlife to have access to the remains but would limit their ability to remove or relocate the specimens to a finite region. Of particular importance would be the ability of vultures to access the remains as these are often a key component in the decomposition process in Florida. (Figure B-1) Vultures showed great interest in the decomposing remains of the current project (i.e., circling the site, landing on top of the cages) but were unable to directly access the remains to feed due to the presence of the cages.

Finally, it has clearly been established through this dissertation research project and many other previous published studies that decomposition is a temperature dependent process (6, 7, 13, 15, 22). Thus, it follows that research of this nature needs to be conducted with respect to various geographic regions. The TBS/ADD data charts that are produced as a result of this study would likely vary greatly from the Southeast USA (where the current study takes place) to the Northeast, Midwest, or West Coast. Likewise, other countries would need to conduct studies to determine the differences in PMI due to the variations in their climate. Studies utilizing similar methods have been conducted on a short-term basis in other geographic regions with varying success, but for optimal use and application to a forensic death investigation, these studies would need to be conducted with many more replicate trials and should take seasonal variation into account when establishing the methodology for predicting time since death.

APPENDIX A
TABLES

Table A-1. Mean, standard deviation, and standard error of accumulated degree day calculations for all sites expressed in degrees Celsius.

	$Mean_{site}$	Standard $Deviation_{site}$	Standard $Error_{site}$	$Mean_{cert}$	Standard $Deviation_{cert}$	Standard $Error_{cert}$
Trial 1	815.87	673.91	25.655	739.67	621.87	23.674
Trial 2	313.8865	176.9907	12.51513	295.1944	165.9212	11.7324
Trial 3	508.1782	491.3564	36.62354	487.7006	473.8361	35.31765

Table A-2. Total number of calendar days for each trial with the maximum total body score observed and the calendar months in which the trials occurred.

	Trial 1	Trial 2	Trial 3
Total Calendar Days	129	22	56
Maximum TBS	29	35	35
Months of the Year	January through June	June	July through August

Table A-3. Total precipitation observed for each trial and precipitation levels at midpoint expressed in inches.

	Trial 1	Trial 2	Trial 3
Total Precipitation	11.89	8.06	4.18
Precipitation at Midpoint	5.83	7.09	0.89

Table A-4. Equations representing the exponential relationships between total body score and accumulated degree days and the R^2 values representing the quality of fit of the equations to the data

	TRIAL 1$_{SITE}$	TRIAL 1$_{CERT}$	TRIAL 2$_{SITE}$	TRIAL 2$_{CERT}$	TRIAL 3$_{SITE}$	TRIAL 3$_{CERT}$
PIG 1	$Y = 40.566E^{0.1313X}$ $R^2 = 0.924$	$Y = 30.503E^{0.1391X}$ $R^2 = 0.9093$	$Y = 27.335E^{0.1086X}$ $R^2 = 0.9739$	$Y = 26.484E^{0.1065X}$ $R^2 = 0.9742$	$Y = 18.658E^{0.1242X}$ $R^2 = 0.8745$	$Y = 17.944E^{0.125X}$ $R^2 = 0.8764$
PIG 2	$Y = 30.065E^{0.1257X}$ $R^2 = 0.8537$	$Y = 22.793E^{0.1315X}$ $R^2 = 0.8532$	$Y = 31.153E^{0.0971X}$ $R^2 = 0.9699$	$Y = 29.312E^{0.0975X}$ $R^2 = 0.9677$	$Y = 19.028E^{0.1339X}$ $R^2 = 0.9509$	$Y = 17.827E^{0.1351X}$ $R^2 = 0.9516$
PIG 3	$Y = 27.559E^{0.1713X}$ $R^2 = 0.9481$	$Y = 20.857E^{0.1807X}$ $R^2 = 0.9366$	$Y = 27.797E^{0.1026X}$ $R^2 = 0.9451$	$Y = 25.415E^{0.1037X}$ $R^2 = 0.9455$	$Y = 18.408E^{0.1304X}$ $R^2 = 0.9582$	$Y = 17.103E^{0.1314X}$ $R^2 = 0.958$
PIG 4	$Y = 30.838E^{0.1398X}$ $R^2 = 0.8979$	$Y = 23.205E^{0.1478X}$ $R^2 = 0.8896$	$Y = 35.88E^{0.0871X}$ $R^2 = 0.9544$	$Y = 31.415E^{0.0894X}$ $R^2 = 0.9513$	$Y = 17.561E^{0.1209X}$ $R^2 = 0.9213$	$Y = 15.712E^{0.1224X}$ $R^2 = 0.9227$
PIG 5	$Y = 39.033E^{0.1301X}$ $R^2 = 0.9421$	$Y = 29.906E^{0.1362X}$ $R^2 = 0.9248$	$Y = 37.266E^{0.0754X}$ $R^2 = 0.9426$	$Y = 31.415E^{0.0894X}$ $R^2 = 0.9513$	$Y = 17.197E^{0.122X}$ $R^2 = 0.8913$	$Y = 15.995E^{0.1231X}$ $R^2 = 0.8932$
PIG 6	$Y = 36.188E^{0.1313X}$ $R^2 = 0.9613$	$Y = 27.782E^{0.139X}$ $R^2 = 0.9444$	$Y = 34.367E^{0.083X}$ $R^2 = 0.9762$	$Y = 31.192E^{0.0841X}$ $R^2 = 0.9736$	$Y = 18.759E^{0.1374X}$ $R^2 = 0.9565$	$Y = 17.65E^{0.1389X}$ $R^2 = 0.9581$
PIG 7	$Y = 33.799E^{0.137X}$ $R^2 = 0.9553$	$Y = 25.932E^{0.1438X}$ $R^2 = 0.9399$	$Y = 36.825E^{0.0819X}$ $R^2 = 0.9471$	$Y = 33.876E^{0.0829X}$ $R^2 = 0.9449$	$Y = 15.974E^{0.1299X}$ $R^2 = 0.9241$	$Y = 14.81E^{0.131X}$ $R^2 = 0.924$
PIG 8	$Y = 33.868E^{0.1501X}$ $R^2 = 0.9318$	$Y = 25.855E^{0.1587X}$ $R^2 = 0.9181$	$Y = 31.762E^{0.0854X}$ $R^2 = 0.9556$	$Y = 28.395E^{0.0869X}$ $R^2 = 0.9549$	$Y = 16.732E^{0.1294X}$ $R^2 = 0.9277$	$Y = 15.525E^{0.1299X}$ $R^2 = 0.9279$
PIG 9	$Y = 15.732E^{0.2042X}$ $R^2 = 0.9331$	$Y = 10.925E^{0.2175X}$ $R^2 = 0.9279$	$Y = 25.208E^{0.1093X}$ $R^2 = 0.9422$	$Y = 23.392E^{0.1107X}$ $R^2 = 0.9422$	$Y = 16.371E^{0.129X}$ $R^2 = 0.9166$	$Y = 15.211E^{0.1298X}$ $R^2 = 0.9185$
PIG 10	$Y = 13.584E^{0.2094X}$ $R^2 = 0.9358$	$Y = 10.406E^{0.2163X}$ $R^2 = 0.9335$	$Y = 28.568E^{0.0948X}$ $R^2 = 0.9716$	$Y = 26.435E^{0.0958X}$ $R^2 = 0.9715$	$Y = 15.143E^{0.1334X}$ $R^2 = 0.9447$	$Y = 14.238E^{0.1344X}$ $R^2 = 0.9458$
OVERALL	$Y = 37.04E^{0.1373X}$ $R^2 = 0.8584$	$Y = 28.33E^{0.1445X}$ $R^2 = 0.8482$	$Y = 34.66E^{0.0874X}$ $R^2 = 0.9165$	$Y = 31.94E^{0.0882X}$ $R^2 = 0.9157$	$Y = 18.244E^{0.1265X}$ $R^2 = 0.91$	$Y = 17.054E^{0.1274X}$ $R^2 = 0.9093$

APPENDIX B
FIGURES

Figure B-1. An example of animal scavenging in a human subject throughout the torso and limbs (i.e. punctures in the skin from vultures) and disarticulation of several bones (including ulna, radius, and mandible) away from the core area of the remains (disarticulated bones placed near decedent by investigators for photographic purposes). Photo courtesy of Author.


A


B

Figure B-2. Pig one from the third trial exemplifying the process of bloating through a TBS change from three to nine within 24 hours. A) Pig one on first day of the trial before bloating began with a TBS score of three. B) Pig one on the second day of the trial fully bloated with a TBS score of nine. Photos courtesy of Author.


Figure B-3. An example of marbling present in the torso and left arm of a human subject. Photo courtesy of Author.


Figure B-4. An example of moist decomposition in a pig from the research study exemplifying leaching of decompositional fluids into surrounding soil and insect colonization of remains. Photo courtesy of Author.

Figure B-5. An example of mummification in a pig from the research site showing dry leathery skin over exposed bone. Photo courtesy of Author.

Figure B-6. An example of purge fluid escaping from the nose and mouth of a human subject which is consistent with the process of decomposition, rather than blood due to trauma. Photo courtesy of Author.

Figure B-7. An example of skin slippage, known as degloving, in the hand of a human subject. Photo courtesy of Author.

Figure B-8. Ariel view of the UF Austin Cary Forest with the research site outlined in blue. Photo courtesy of Author.

Figure B-9. Cage designed to inhibit scavenger activity and interference with specimens. Photo courtesy of Author.

Figure B-10. Staggered layout of pigs at the University of Florida's Austin Cary Forest. Photo courtesy of Author.

Figure B-11. Series of photographs taken each day at research site. A) Overall photograph with photo board on cage. B) Overall photograph of whole pig after cage removal. C) Photograph of head of pig. D) Photograph of torso of pig. E) Photograph of limbs of pig. Photos courtesy of Author.

Head and Neck	
Fresh	
1	Fresh, no discoloration
Early decomposition	
2	Pink-white appearance; skin slippage; hair loss
3	Gray to green discoloration; some flesh still relatively fresh
4	Discoloration and/or brownish shades particularly at edges; drying of nose, ears, and lips
5	Purging of decompositional fluids out of eyes, ears, nose, mouth; bloating of neck and face may be present
6	Brown to black discoloration of flesh
Advanced decomposition	
7	Caving in of the flesh and tissues of eyes and throat
8	Moist decomposition with bone exposure less than ½ that of the area being scored
9	Mummification with bone exposure less than ½ that of the area being scored
Skeletonized	
10	Bone exposure of more than ½ the area being scored with greasy substances and decomposed tissue
11	Bone exposure of more than ½ the area being scored with desiccated or mummified tissue
12	Bones largely dry, but retaining some grease
13	Dry bone
Trunk/Torso	
Fresh	
1	Fresh, no discoloration
Early decomposition	
2	Pink-white appearance; skin slippage and marbling present
3	Gray to green discoloration; some flesh relatively fresh
4	Bloating with green discoloration and purging of decompositional fluids
5	Post-bloating following release of abdominal gases; discoloration changing from green to black
Advanced decomposition	
6	Decomposition of tissue producing sagging of flesh; caving in of abdominal cavity
7	Moist decomposition with bone exposure less than ½ that of the area being scored
8	Mummification with bone exposure of less than ½ that of the area being scored
Skeletonized	
9	Bones with decomposed tissue, sometimes with body fluids and grease still present
10	Bones with desiccated or mummified tissue covering less than ½ of the area being scored
11	Bones largely dry, but retaining some grease
12	Dry bone
Limbs	
Fresh	
1	Fresh, no discoloration
Early decomposition	
2	Pink-white appearance; skin slippage of hands and/or feet
3	Gray to green discoloration; marbling; some flesh still relatively fresh
4	Discoloration and/or brownish shades particularly at edges; drying of fingers, toes, and other projecting extremities
5	Brown to black discoloration; skin having a leathery appearance
Advanced decomposition	
6	Moist decomposition with bone exposure less than ½ that of the area being scored
7	Mummification with bone exposure of less than ½ that of the area being scored
Skeletonized	
8	Bone exposure over ½ the area being scored; some decomposed tissue and body fluids remaining
9	Bones largely dry, but retaining some grease
10	Dry bone

Figure B-12. Total body score chart.


A


B

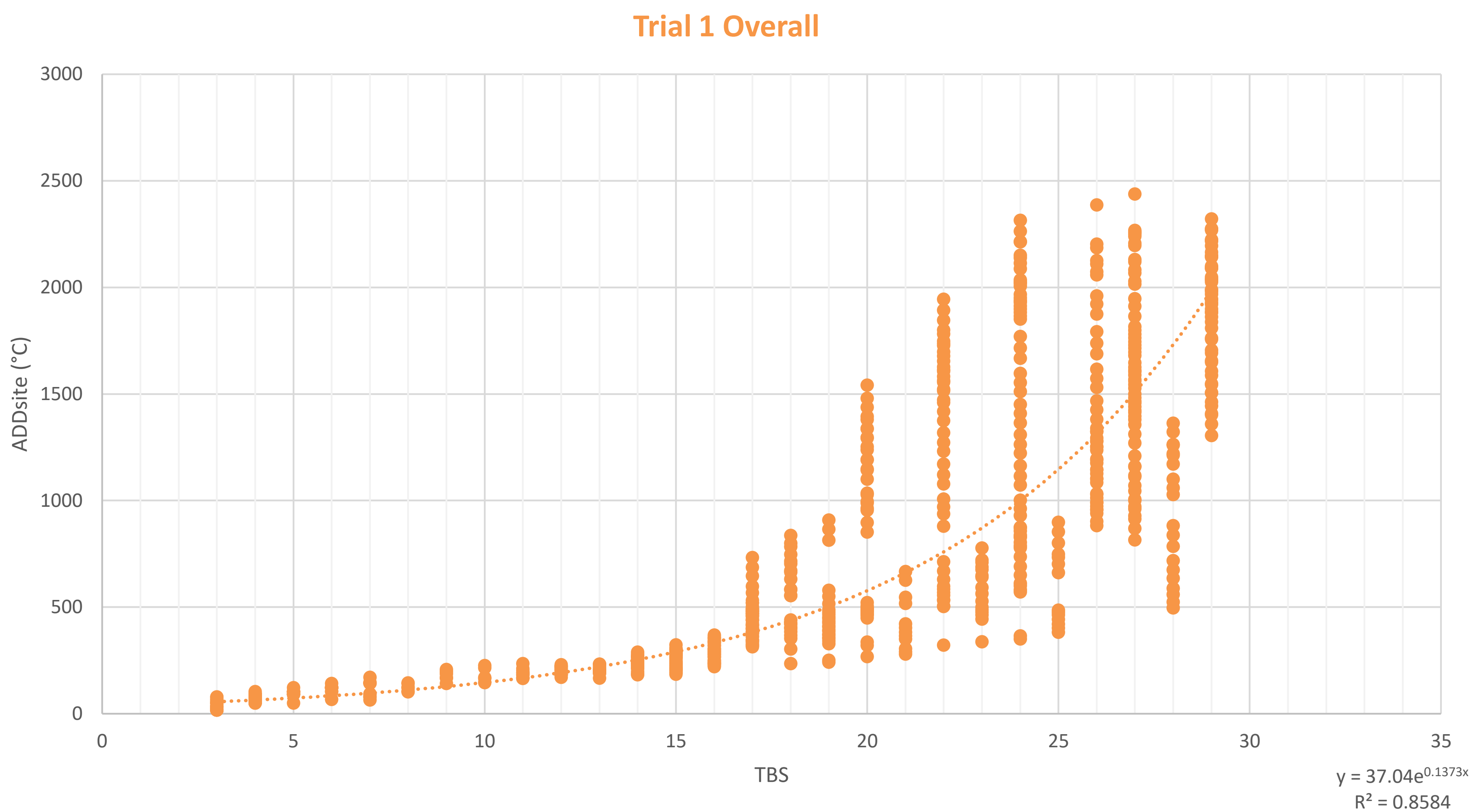
Figure B-13. Examples of stages of decomposition exemplified in the same pig throughout trial two. A) Fresh, B) Early decomposition, C) Advanced decomposition, D) Skeletonization. Photos courtesy of Author.


C


D

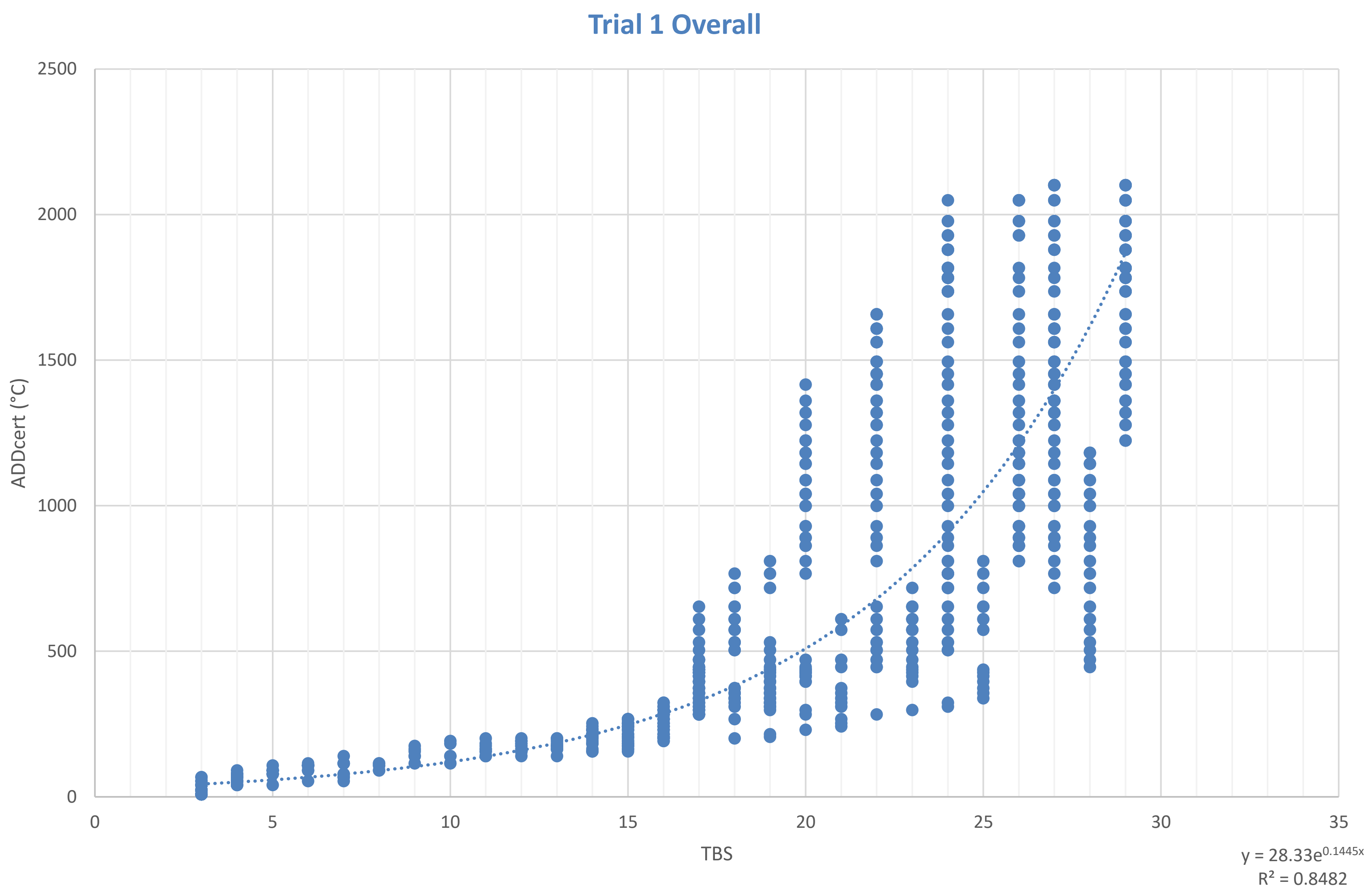
Figure B-13. Continued.

Figure B-14. Example of pig from first trial that had mummified tissue on exposed portions of remains and saponified tissue on the underside of remains at the body-soil interface. Photo courtesy of Author.



A

Figure B-15. Overall charts showing relationship between total body score and accumulated degree days. A) Trial 1 research site temperatures, B) Trial 1 certified temperatures, C) Trial 2 research site temperatures, D) Trial 2 certified temperatures, E) Trial 3 research site temperatures, F) Trial 4 research site temperatures



B

Figure B-15. Continued.

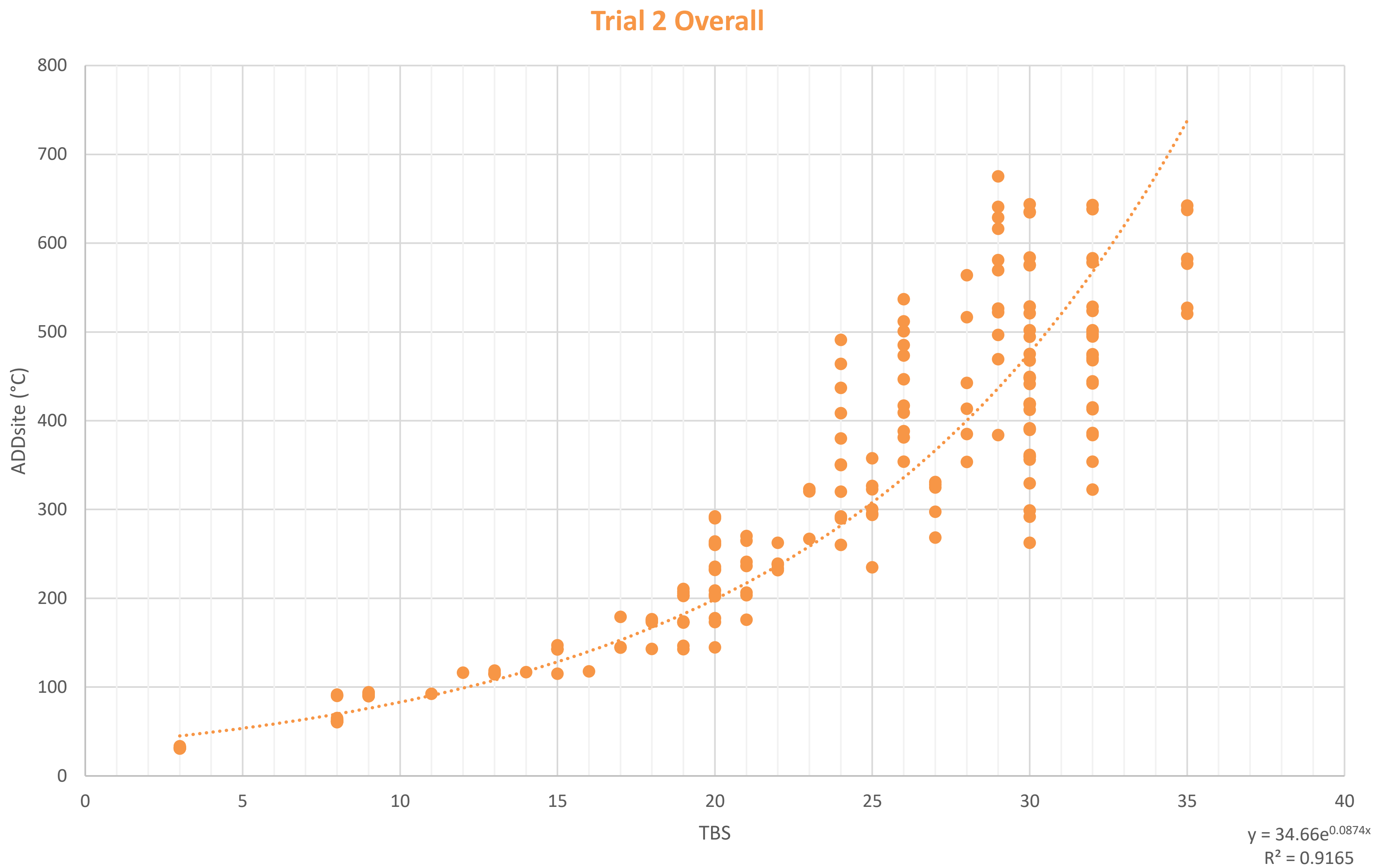


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Figure B-15. Continued.

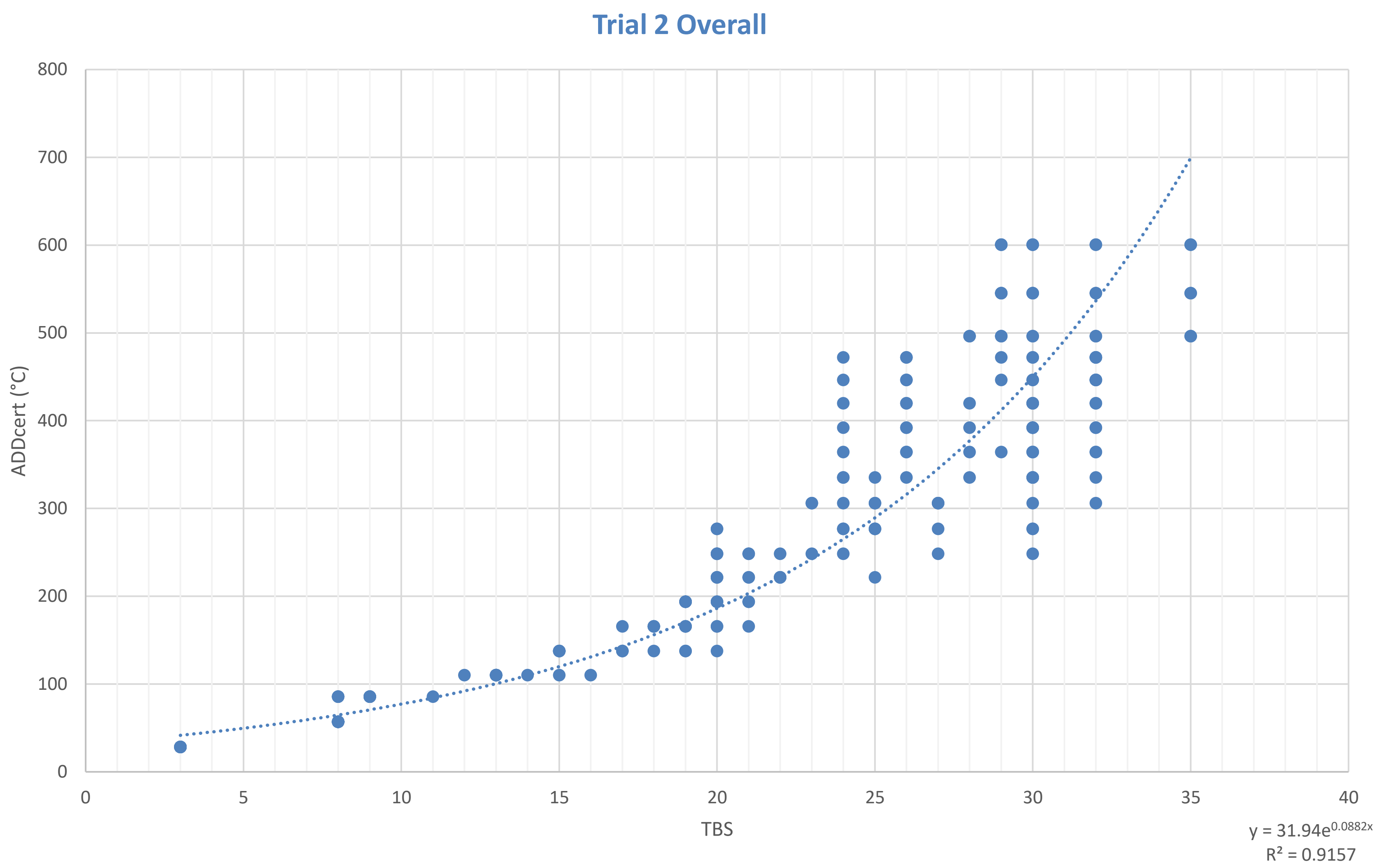

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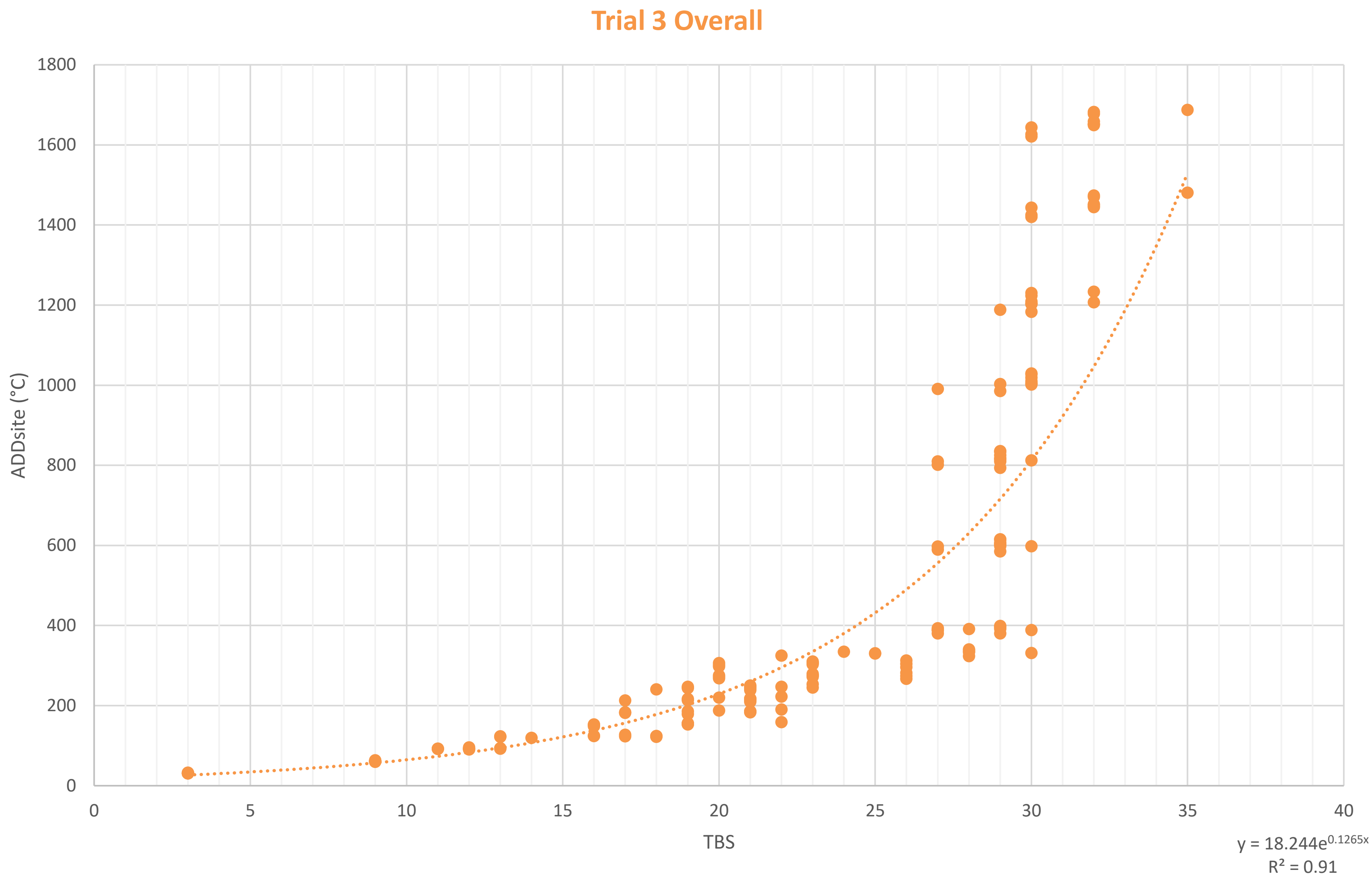
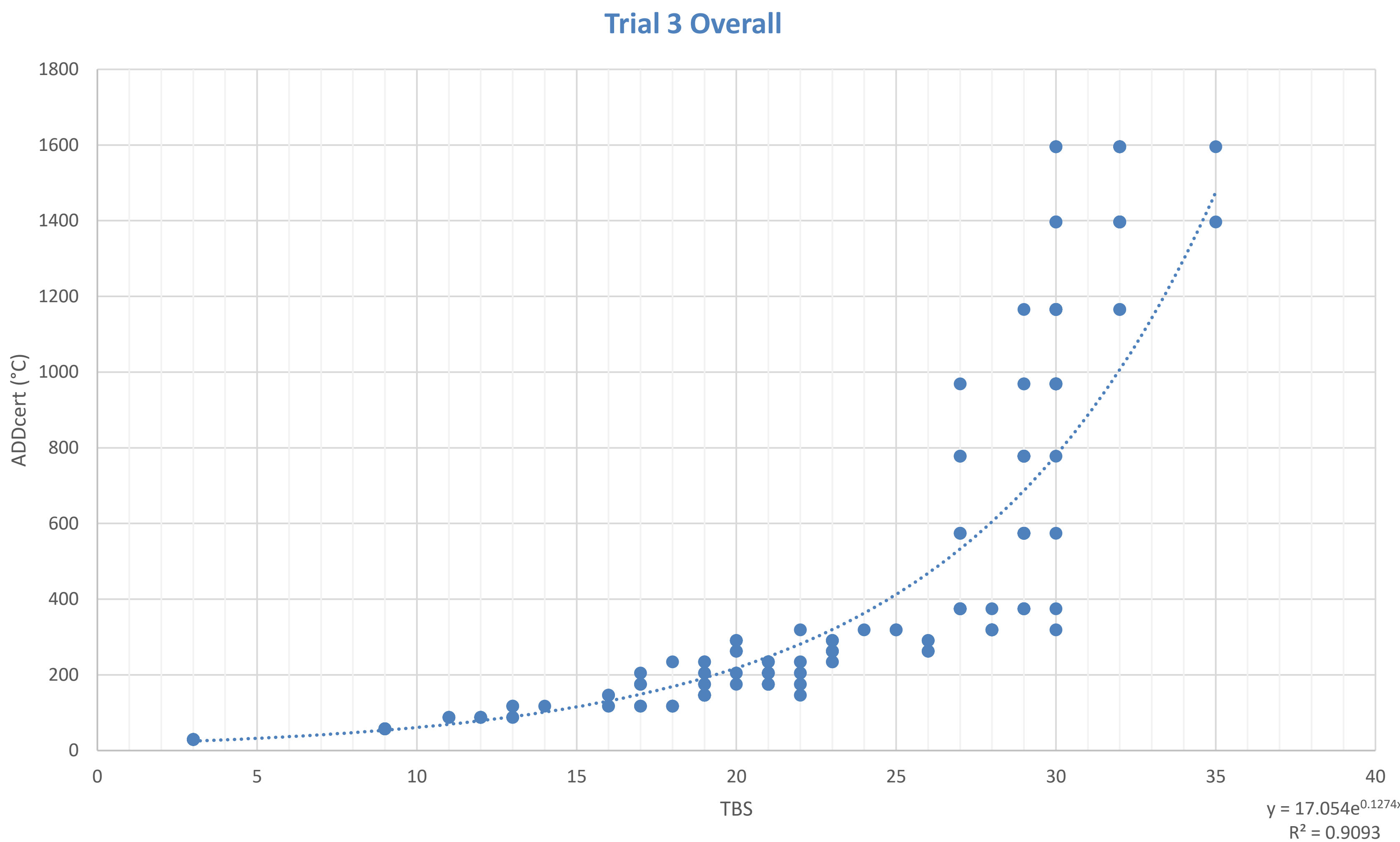
Figure B-15. Continued.



E

Figure B-15. Continued.



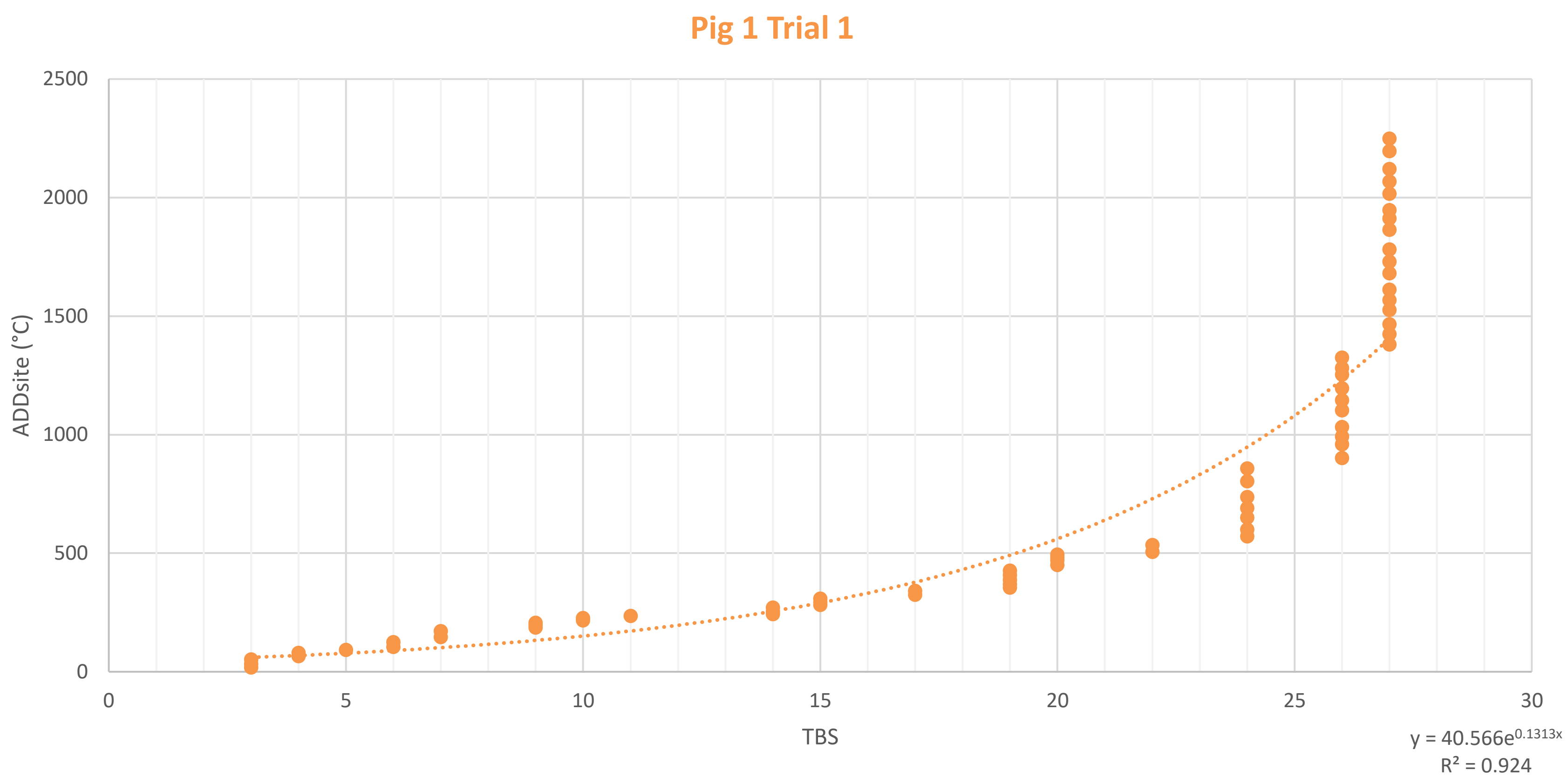
F

Figure B-15. Continued.

Figure B-16. Specimen in the maximum stage of decomposition observed in trial one. Photo courtesy of Author.

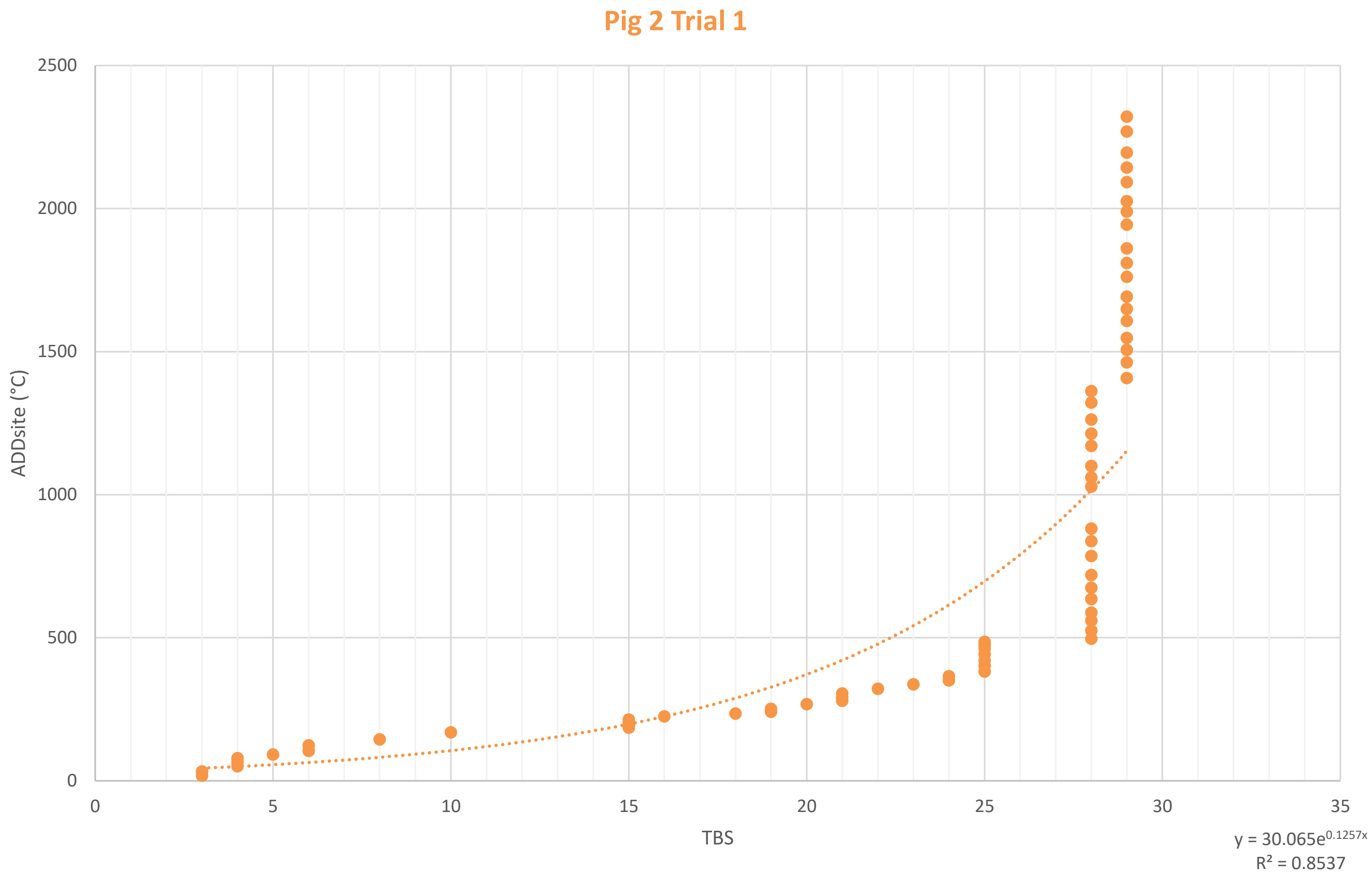
Figure B-17. Specimen in the maximum stage of decomposition observed in trial two. Photo courtesy of Author.

Figure B-18. Specimen in the maximum stage of decomposition observed in trial three. Photo courtesy of Author.



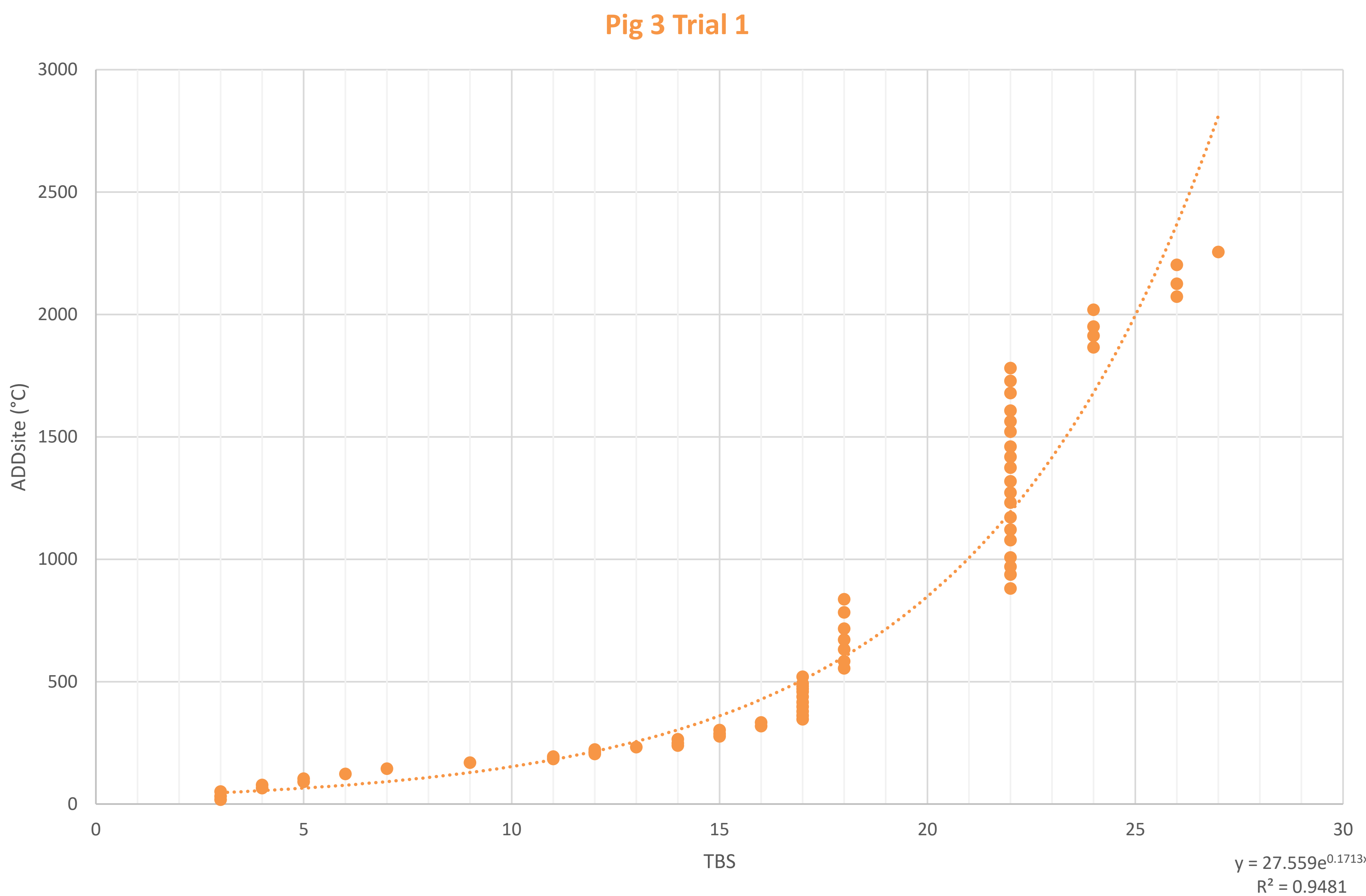
A

Figure B-19. Charts showing relationship between total body score and accumulated degree days for individual specimens in trial one. A) Pig 1 research site temperatures, B) Pig 2 research site temperatures, C) Pig 3 research site temperatures, D) Pig 4 research site temperatures, E) Pig 5 research site temperatures, F) Pig 6 research site temperatures, G) Pig 7 research site temperatures, H) Pig 8 research site temperatures, I) Pig 9 research site temperatures, J) Pig 10 research site temperatures, K) Pig 1 certified temperatures, L) Pig 2 certified temperatures, M) Pig 3 certified temperatures, N) Pig 4 certified temperatures, O) Pig 5 certified temperatures, P) Pig 6 certified temperatures, Q) Pig 7 certified temperatures, R) Pig 8 certified temperatures, S) Pig 9 certified temperatures, T) Pig 10 certified temperatures



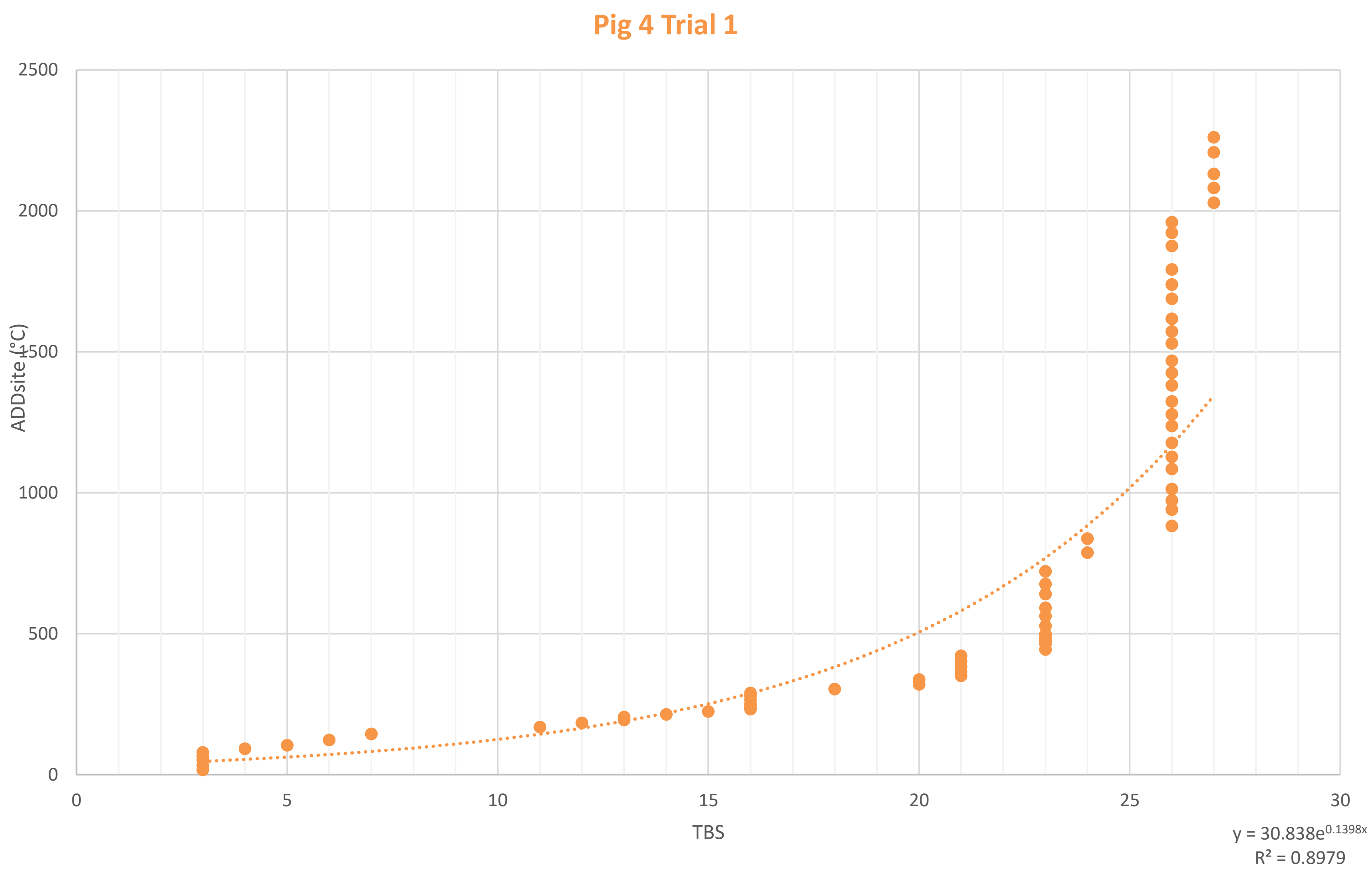
B

Figure B-19. Continued.



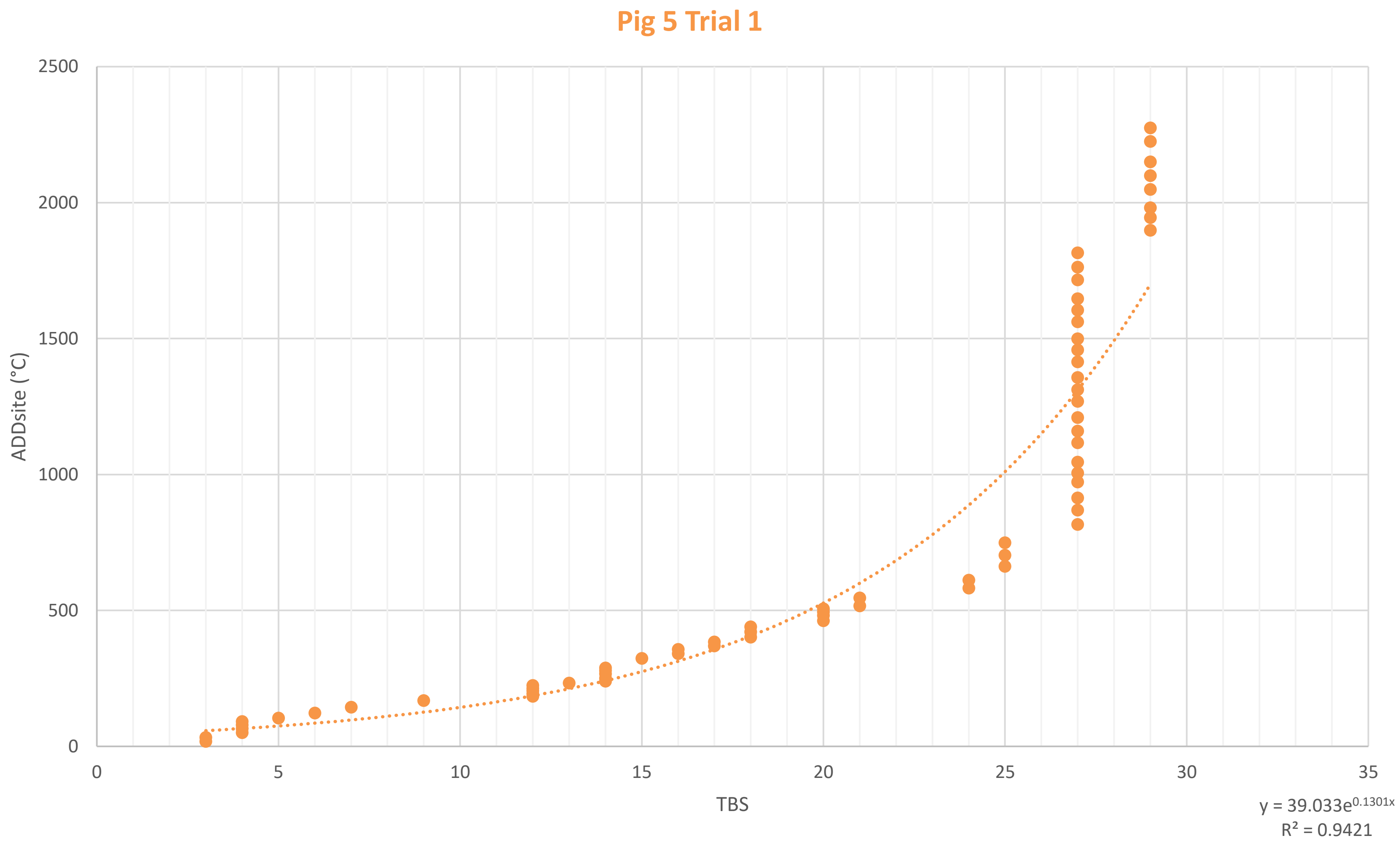
C

Figure B-19. Continued.



D

Figure B-19. Continued.



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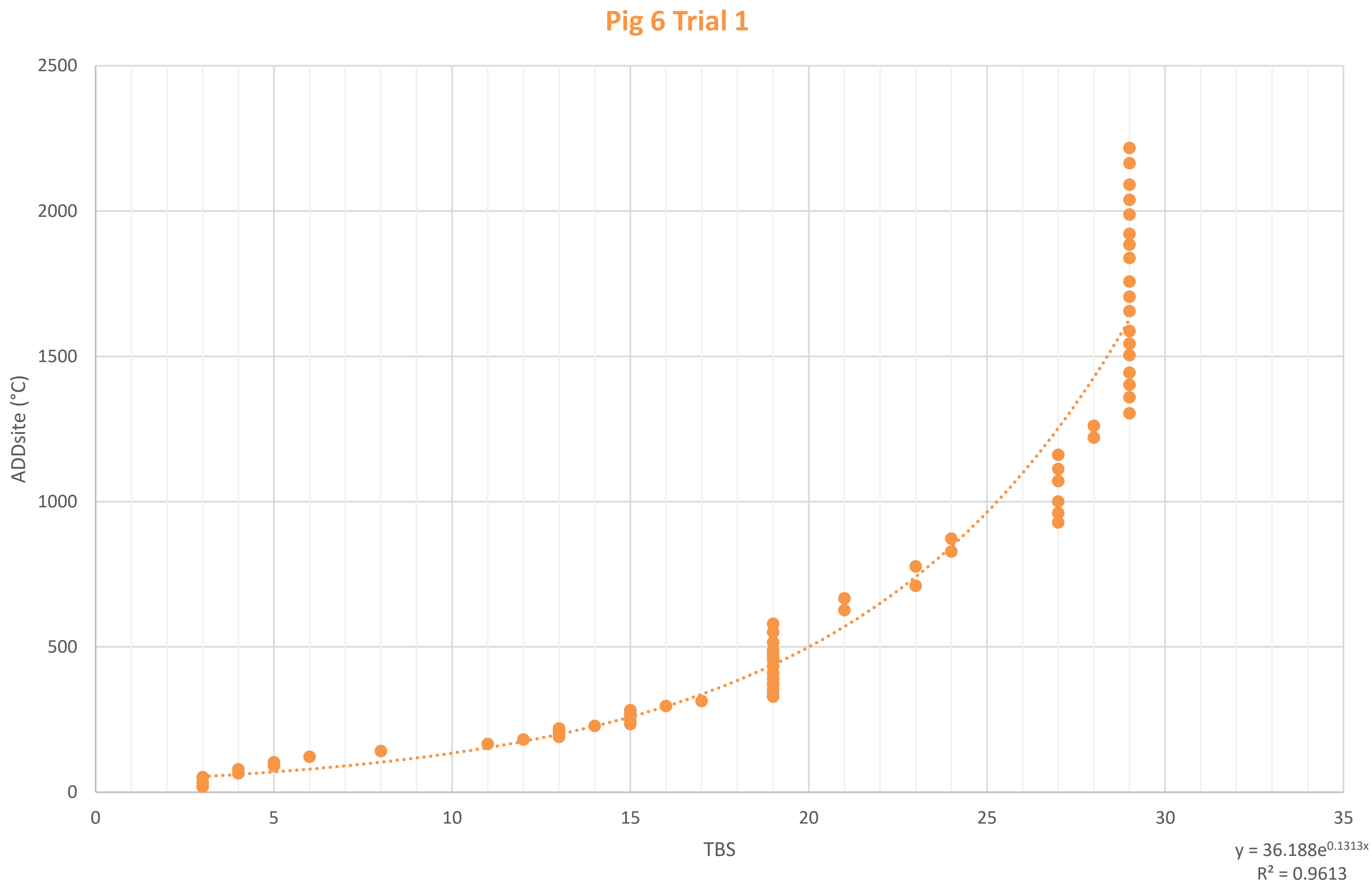

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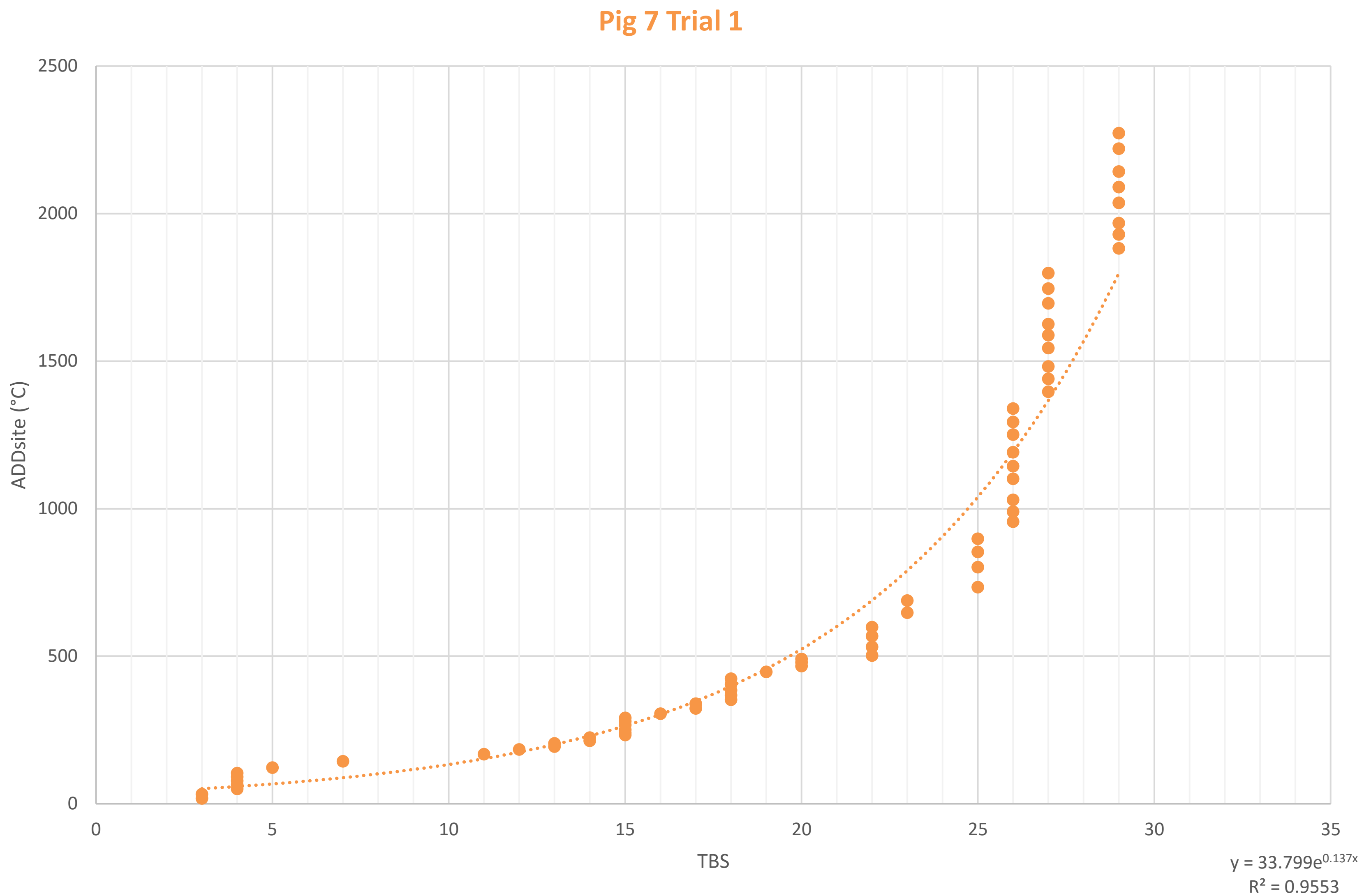

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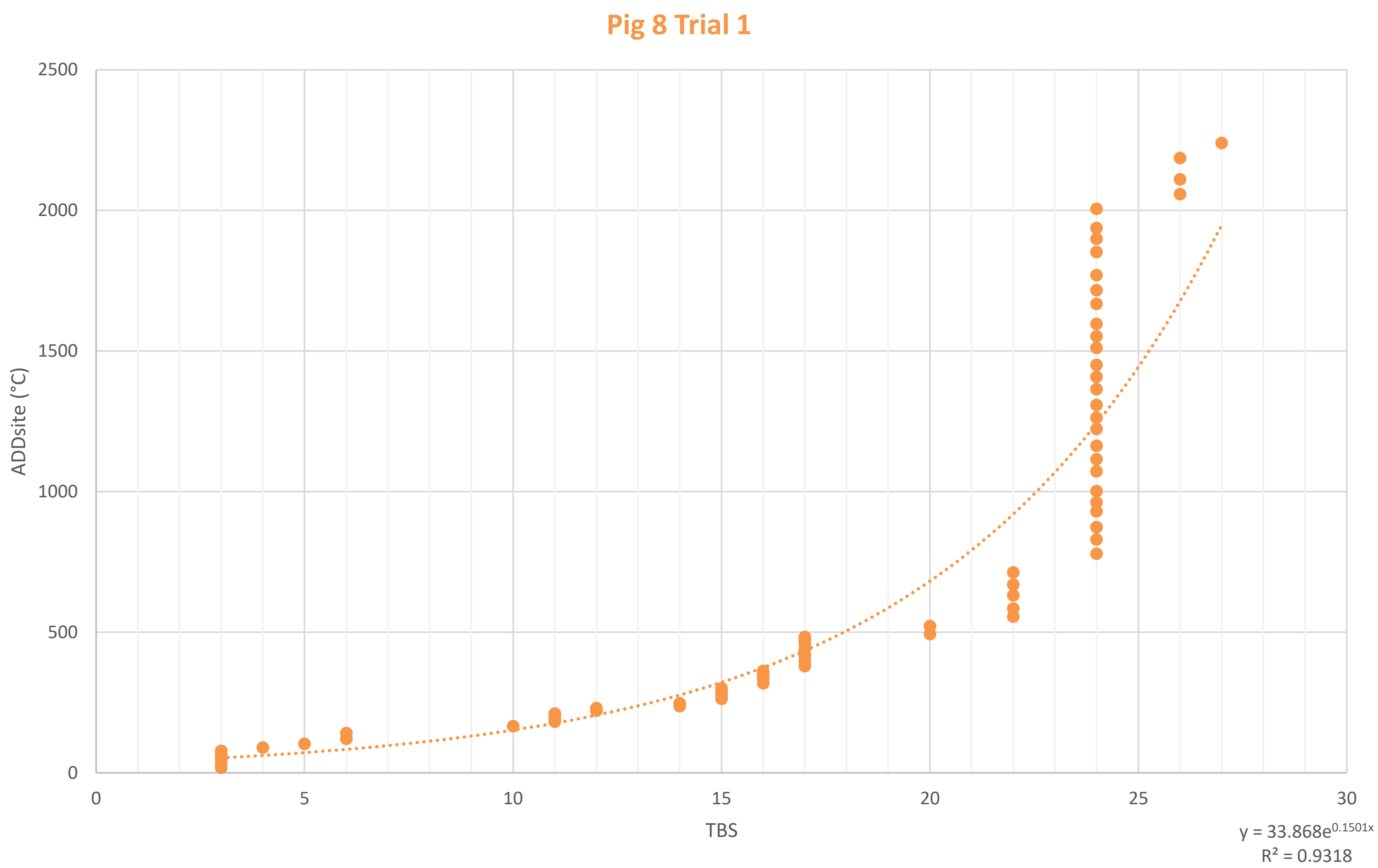

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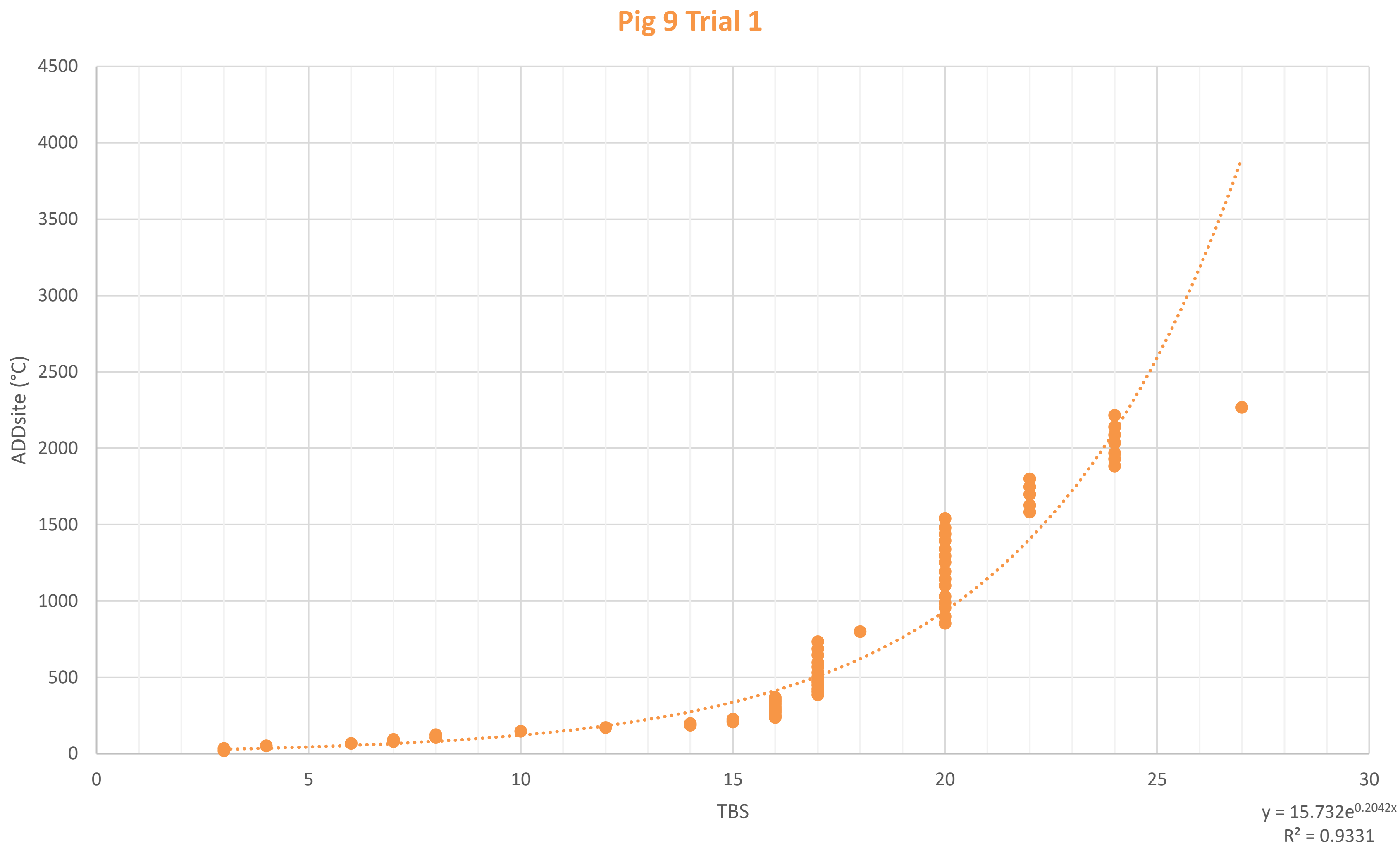

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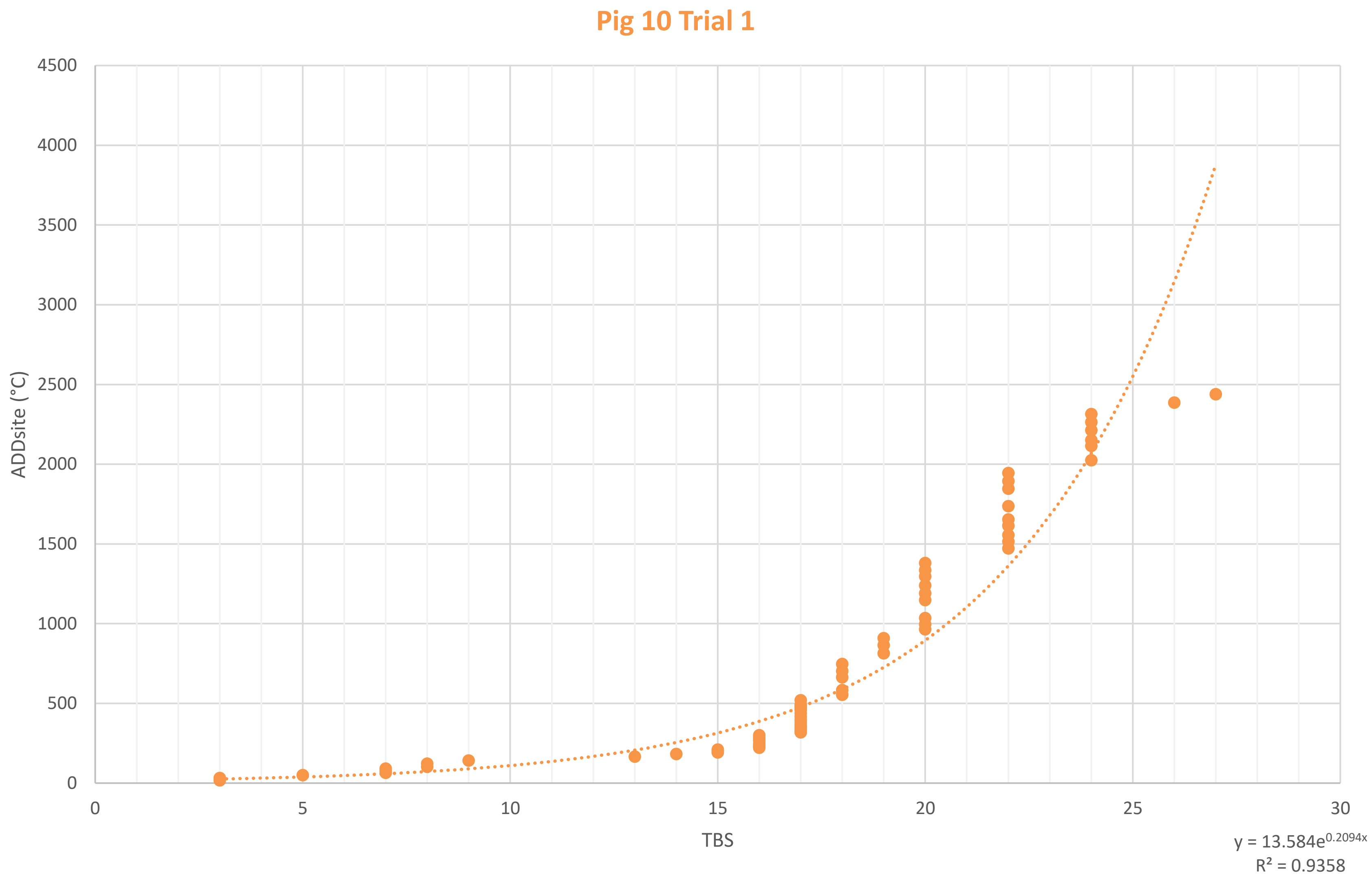

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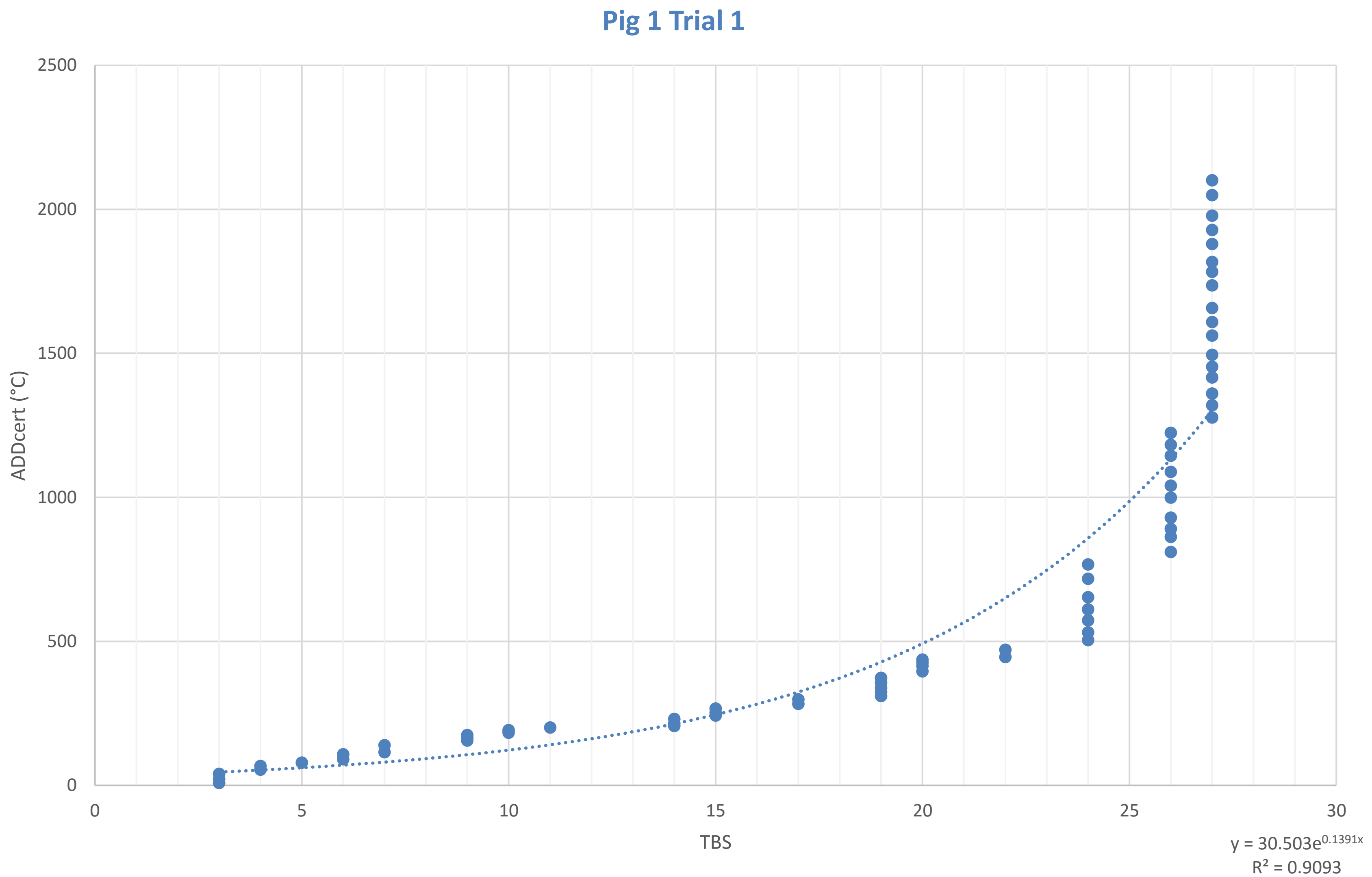

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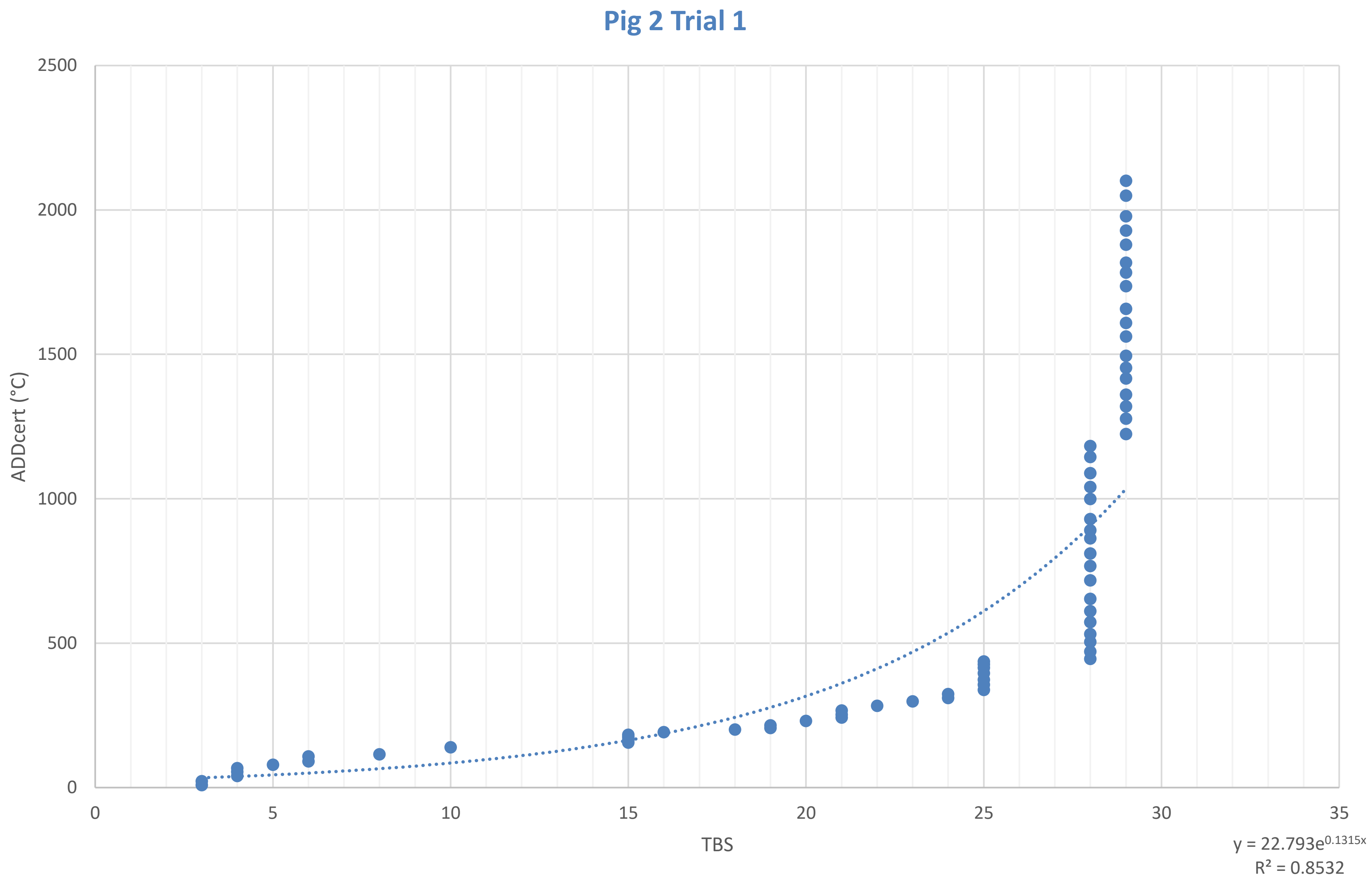

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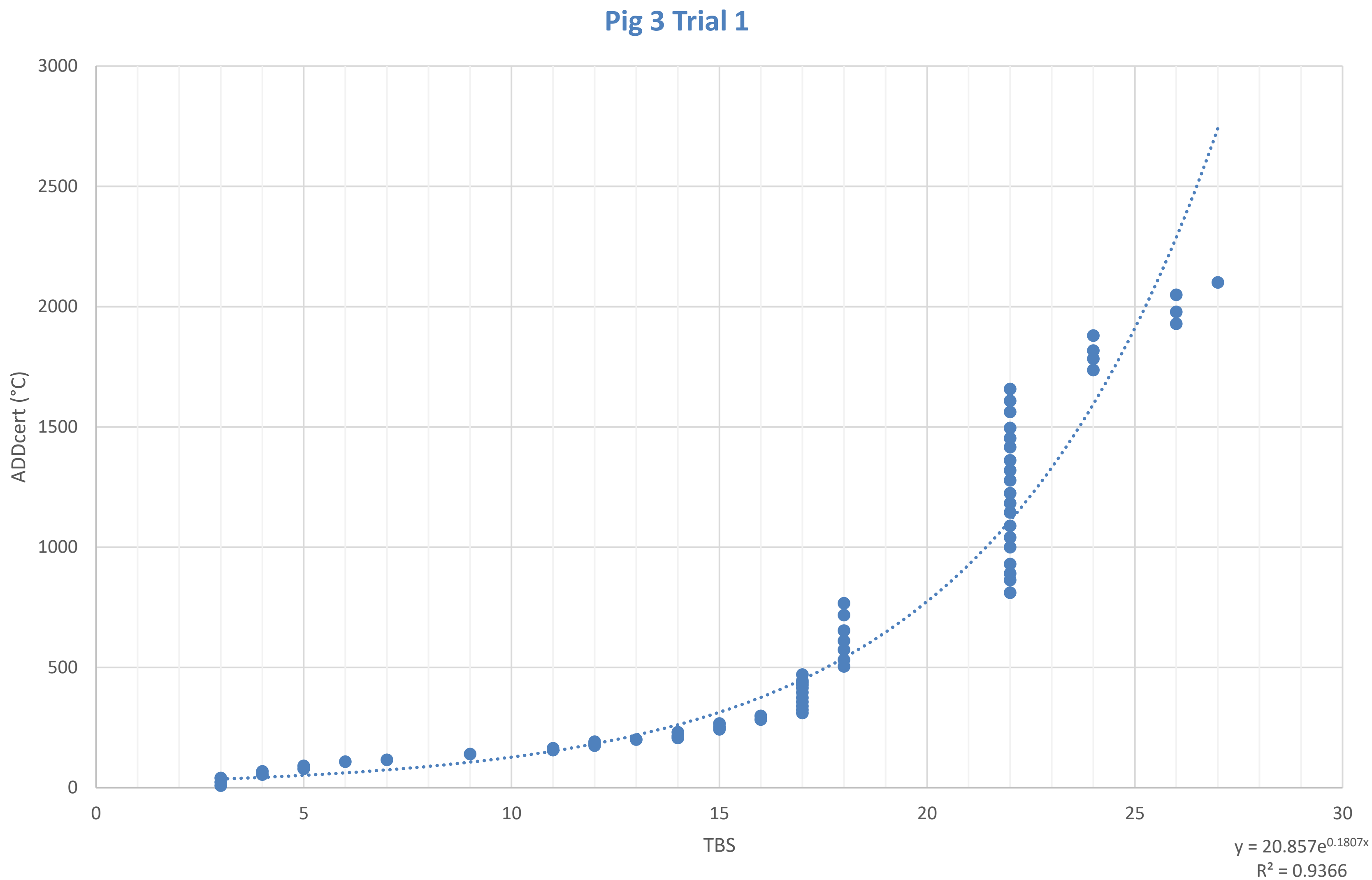

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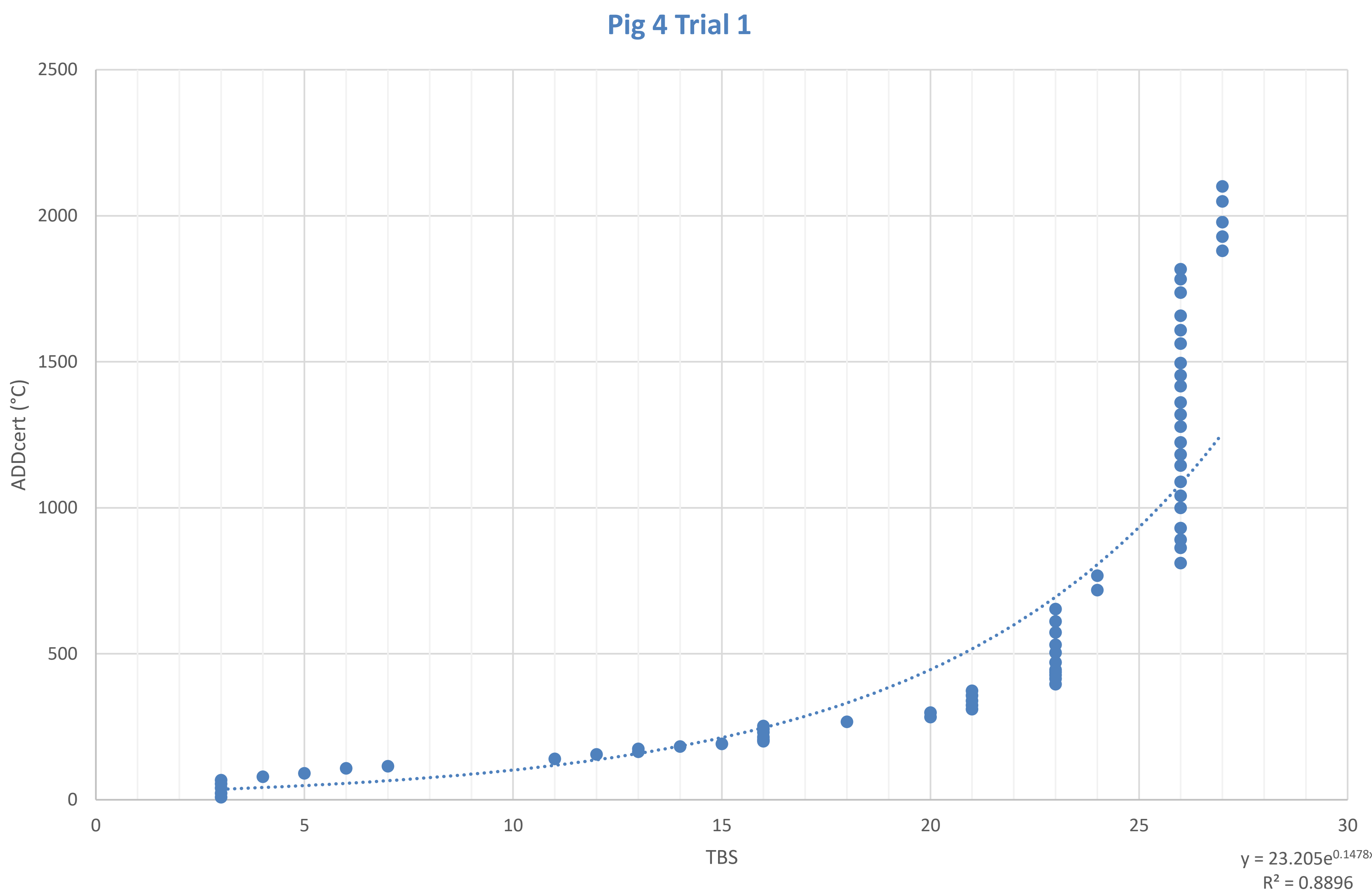

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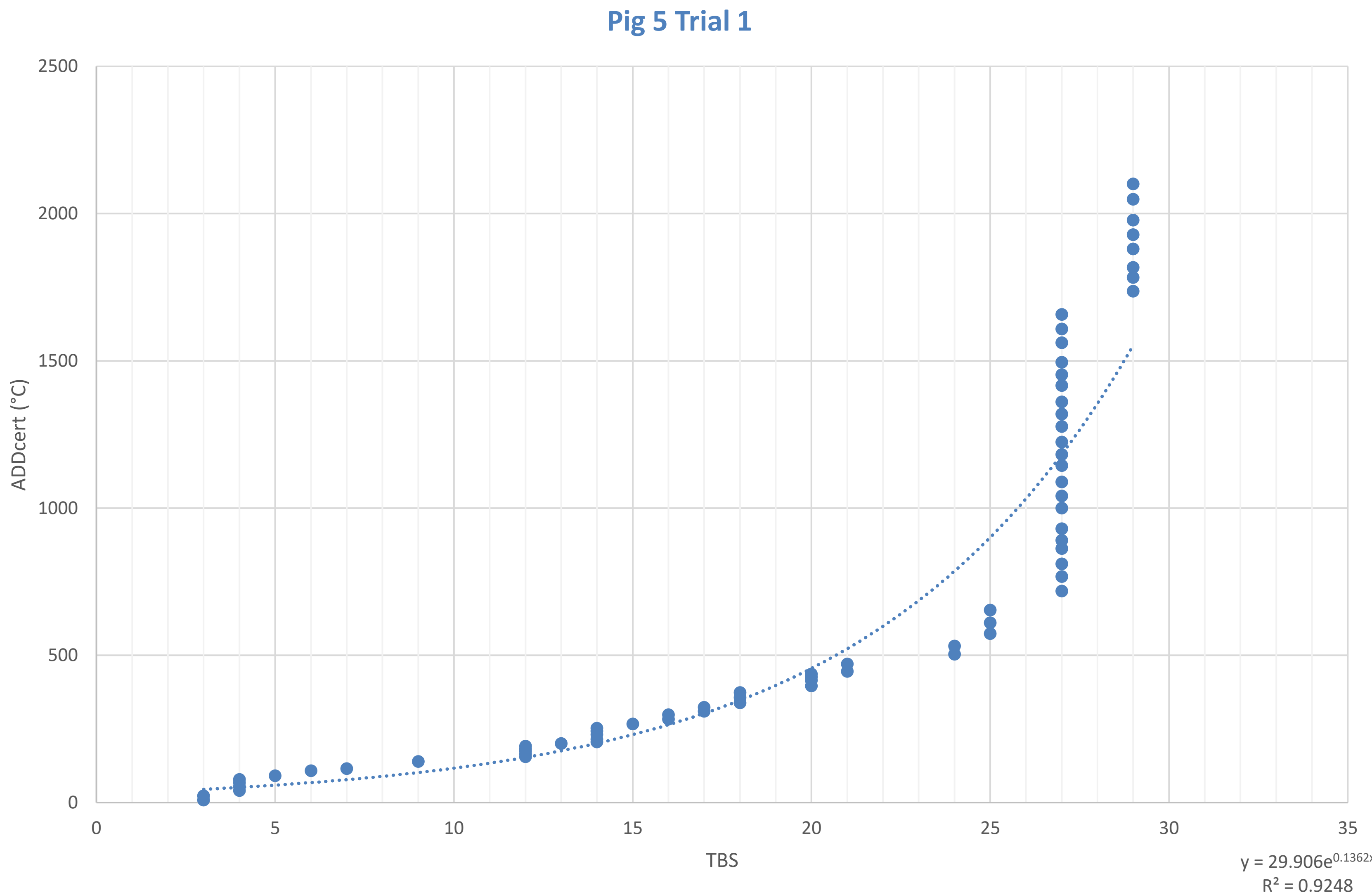

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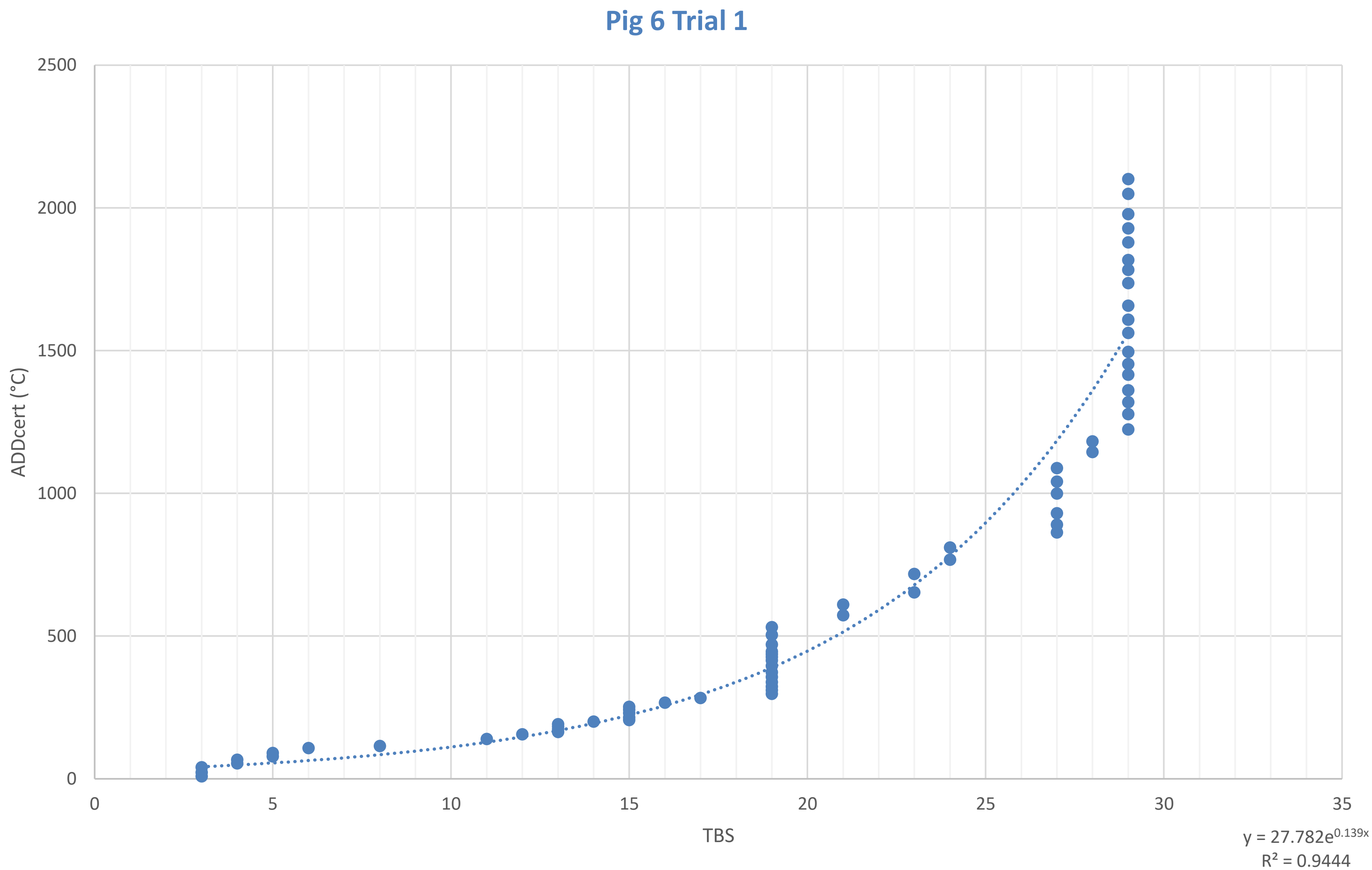

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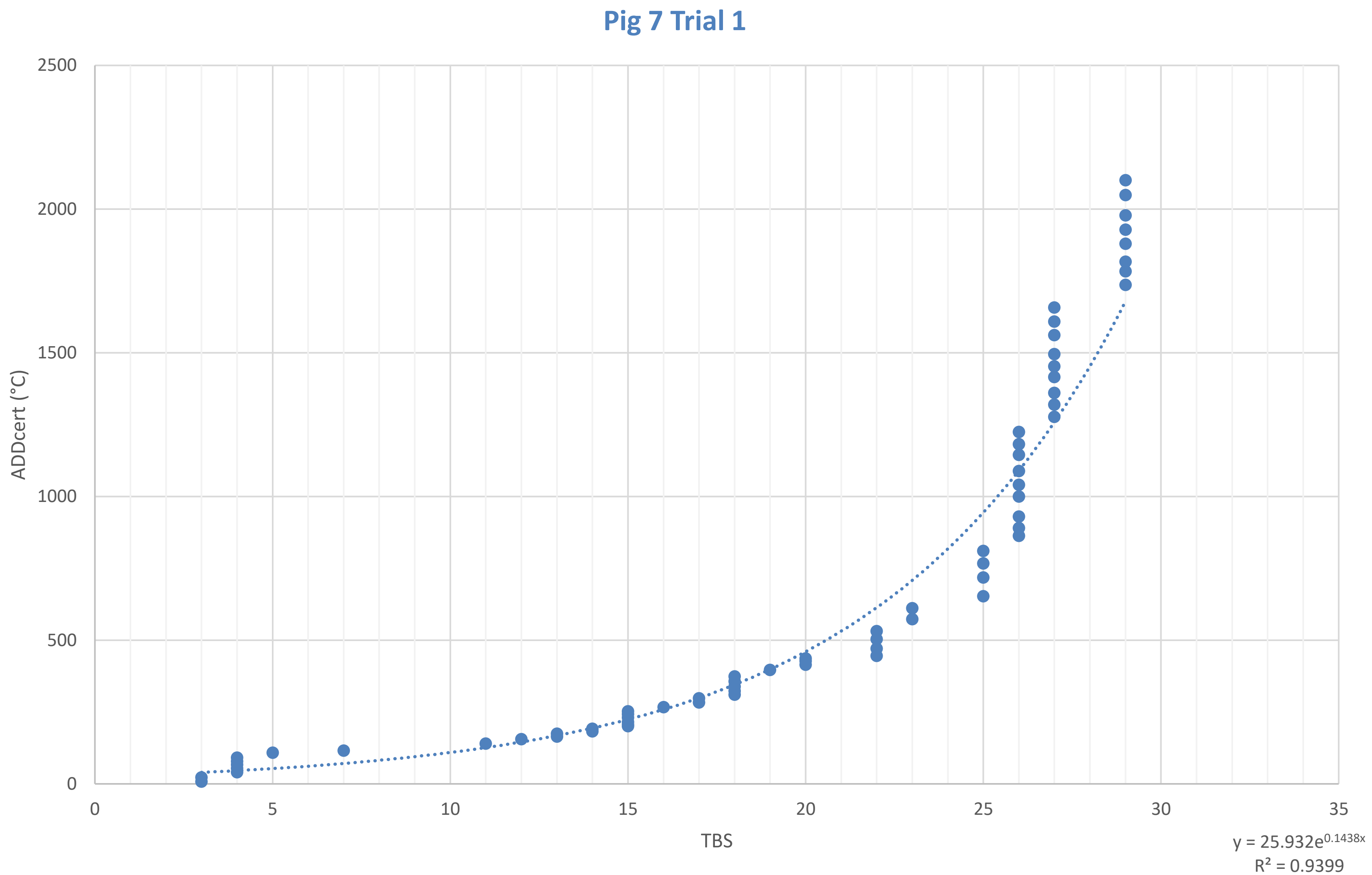

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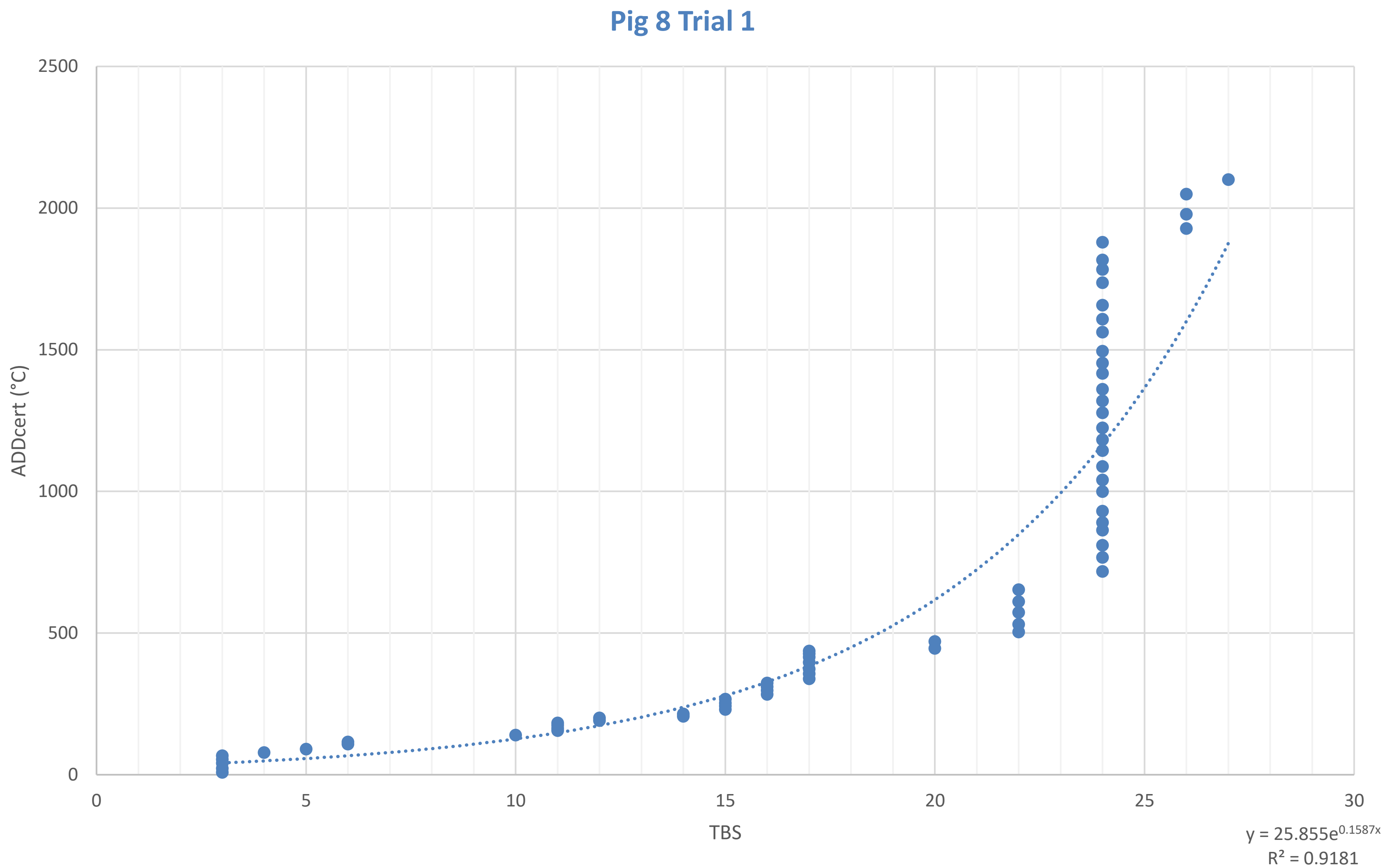

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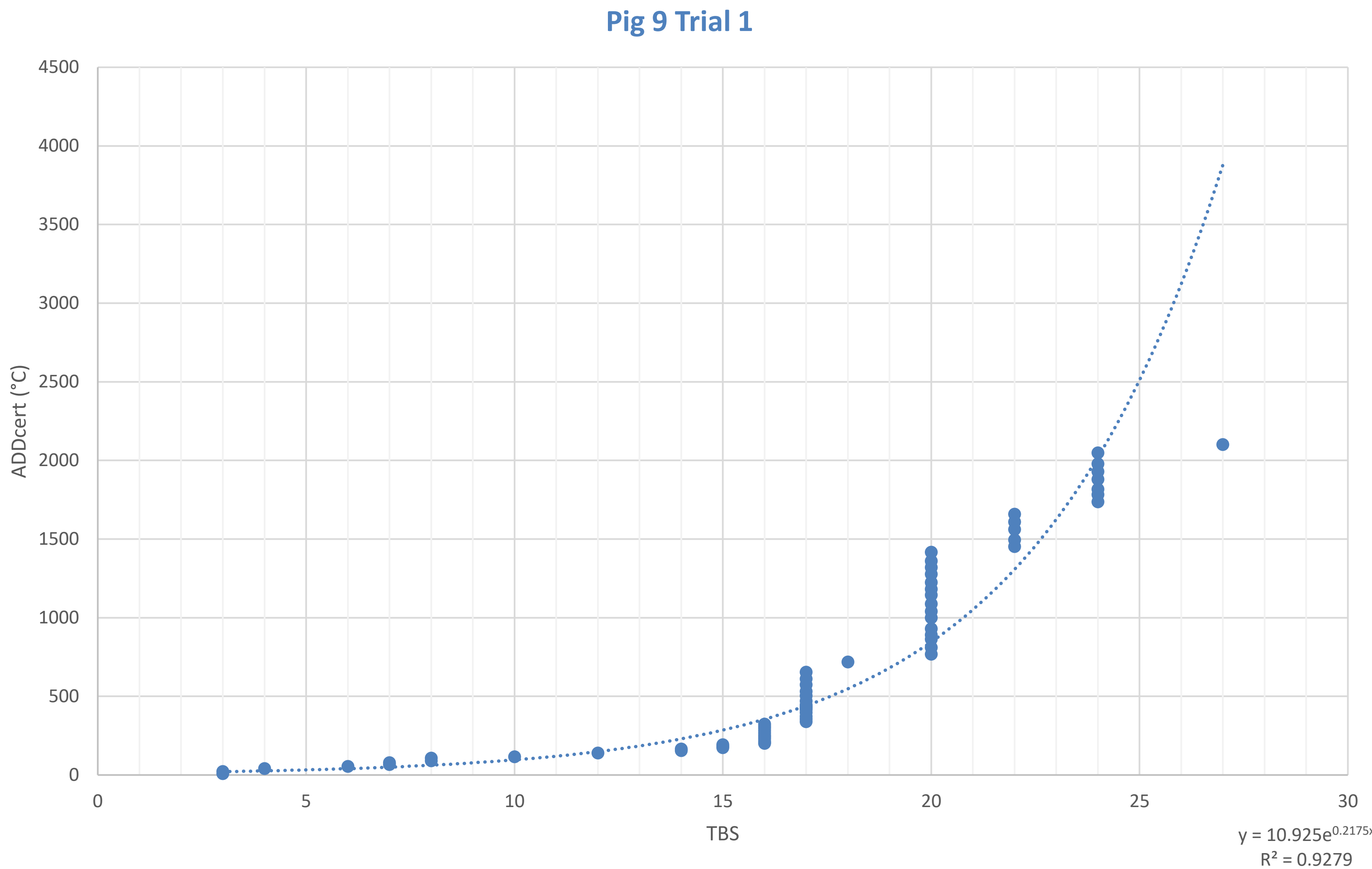

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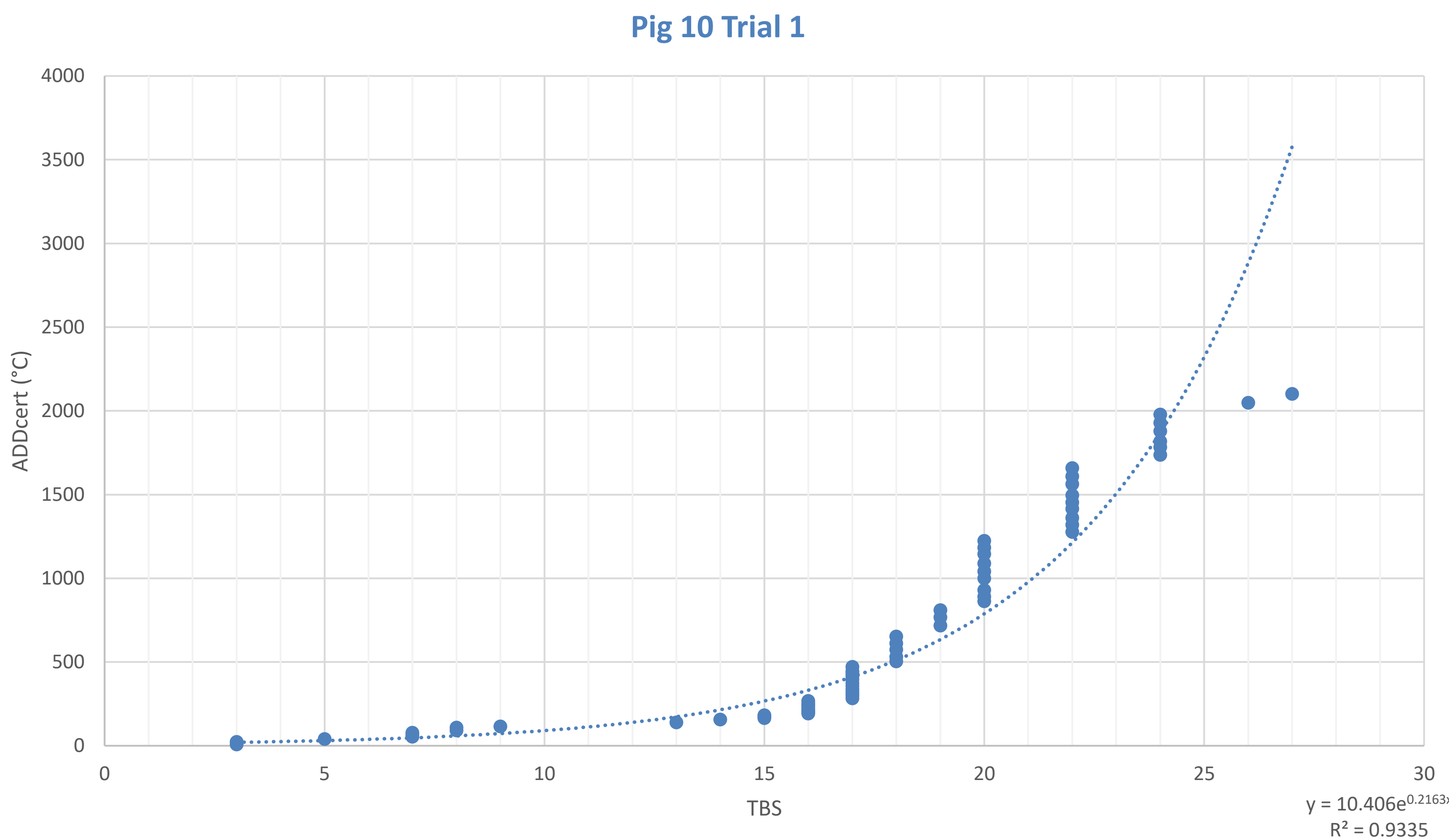

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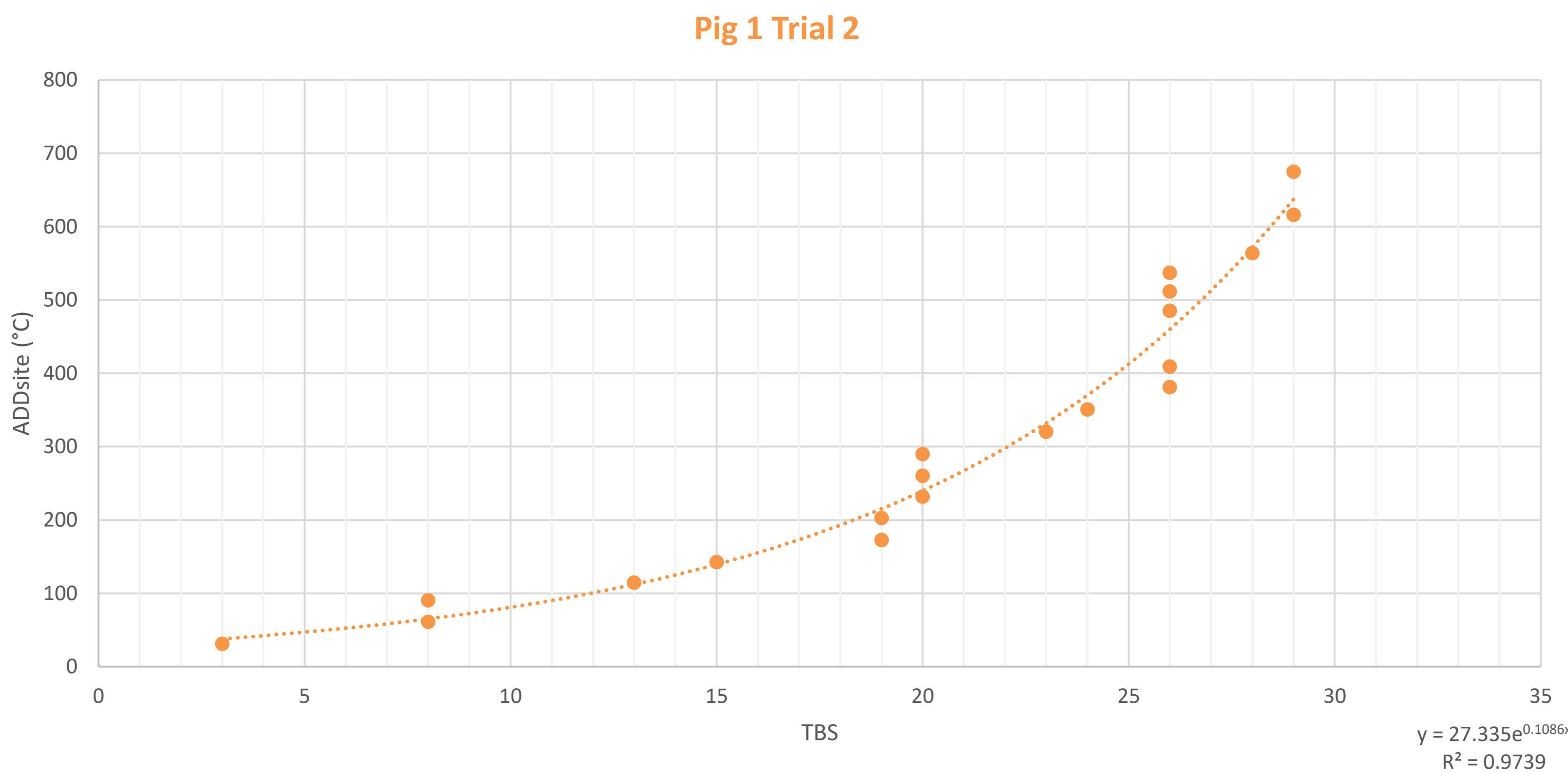
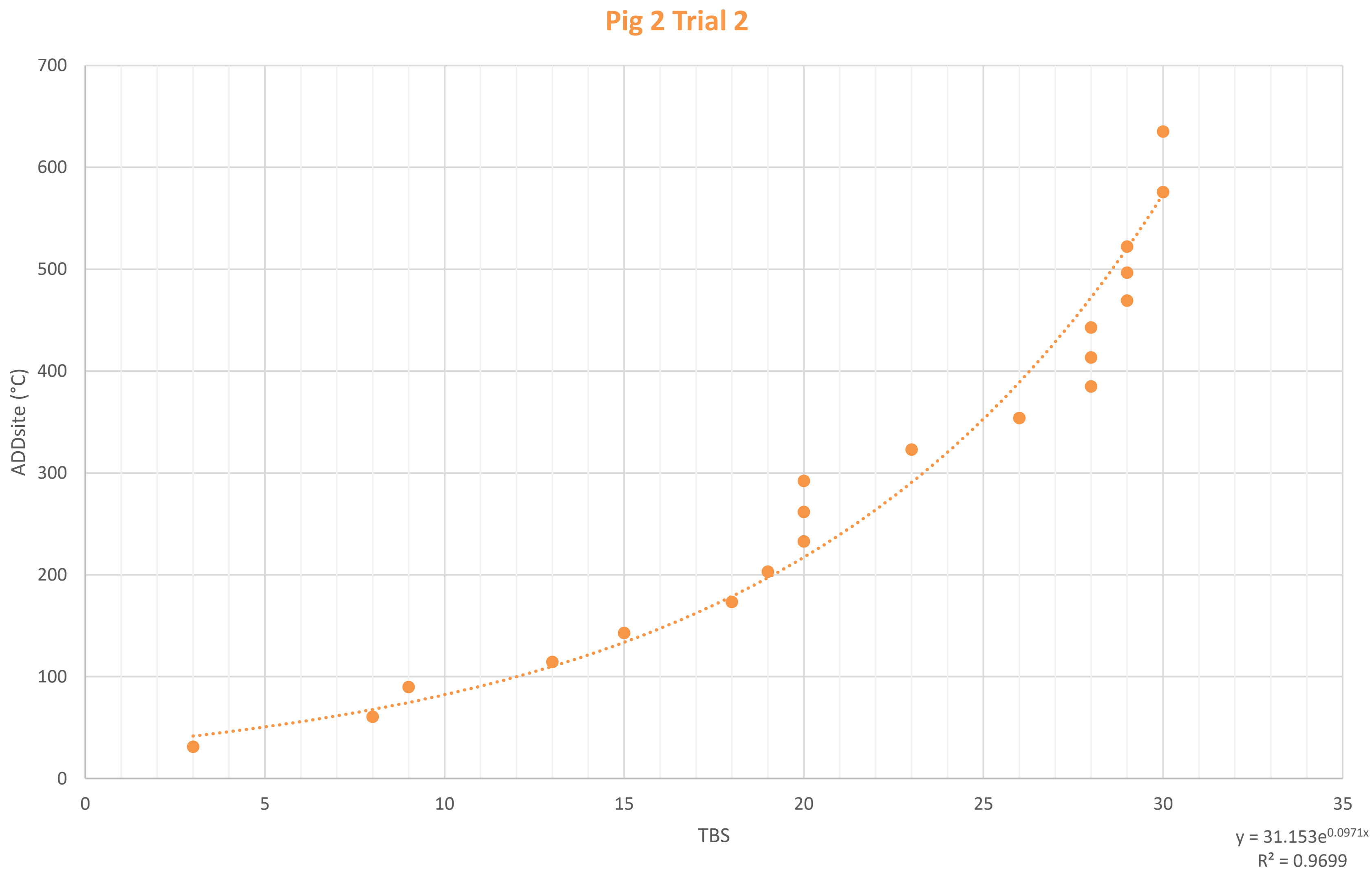


A

Figure B-20. Charts showing relationship between total body score and accumulated degree days for individual specimens in trial two. A) Pig 1 research site temperatures, B) Pig 2 research site temperatures, C) Pig 3 research site temperatures, D) Pig 4 research site temperatures, E) Pig 5 research site temperatures, F) Pig 6 research site temperatures, G) Pig 7 research site temperatures, H) Pig 8 research site temperatures, I) Pig 9 research site temperatures, J) Pig 10 research site temperatures, K) Pig 1 certified temperatures, L) Pig 2 certified temperatures, M) Pig 3 certified temperatures, N) Pig 4 certified temperatures, O) Pig 5 certified temperatures, P) Pig 6 certified temperatures, Q) Pig 7 certified temperatures, R) Pig 8 certified temperatures, S) Pig 9 certified temperatures, T) Pig 10 certified temperatures



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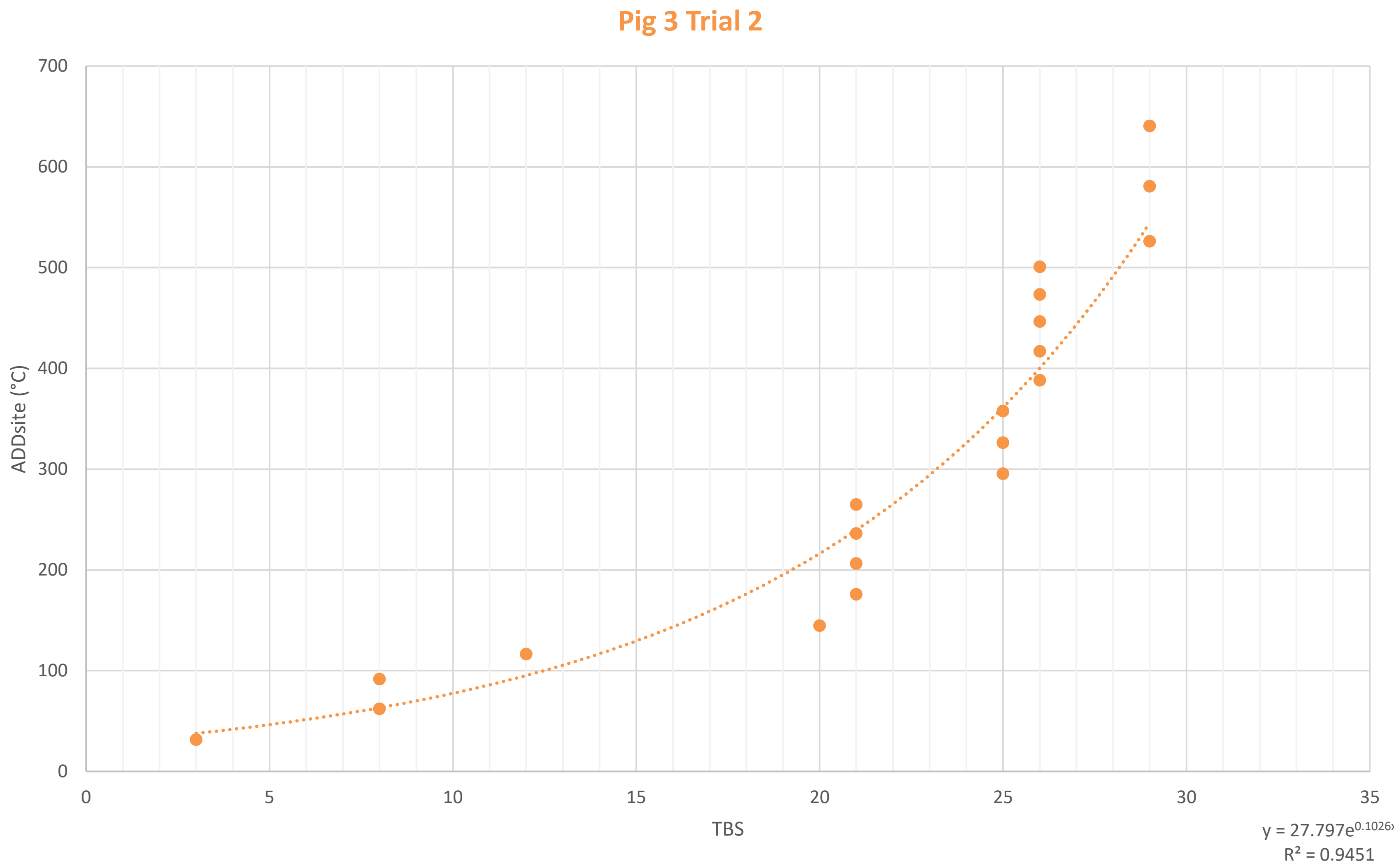

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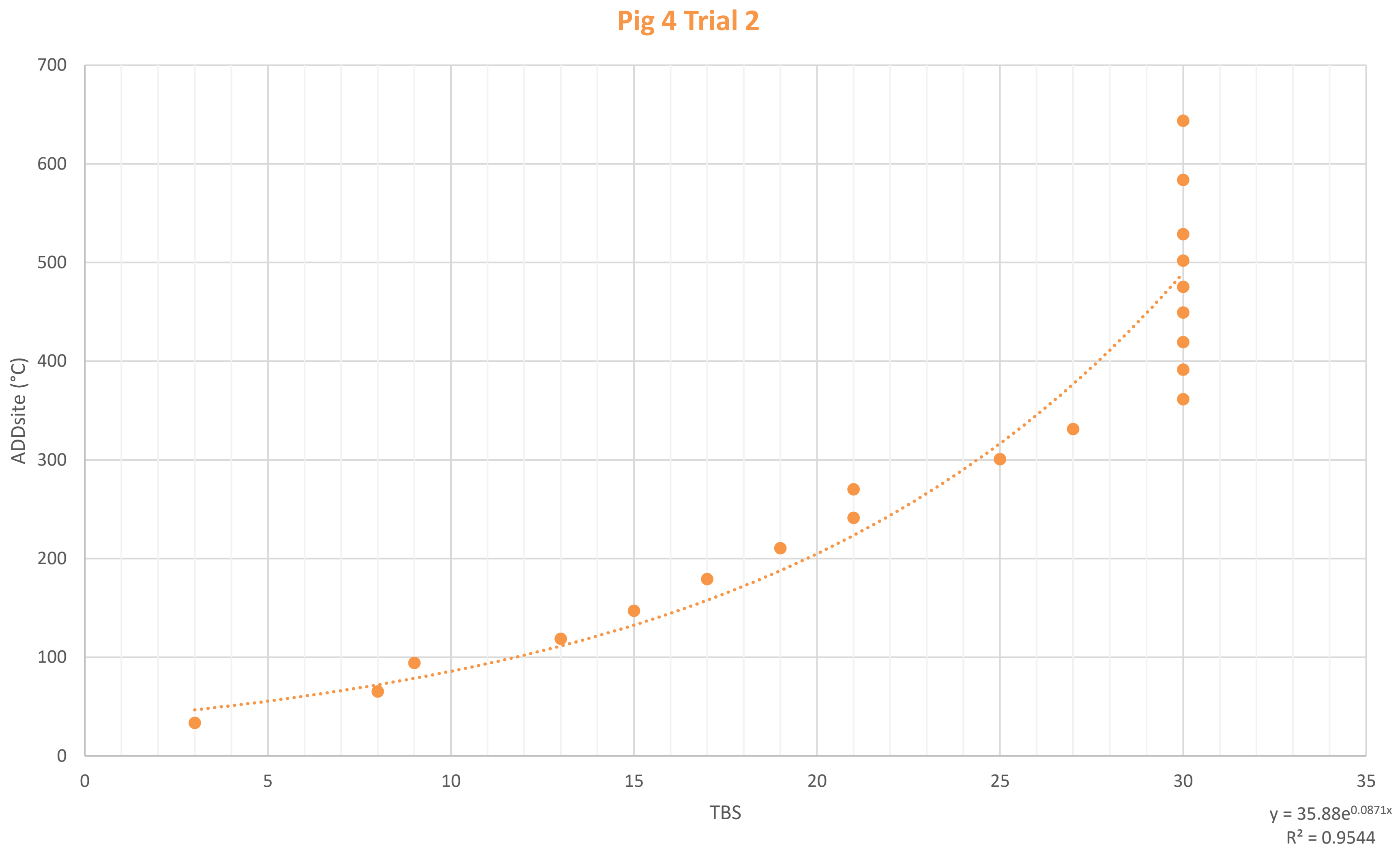

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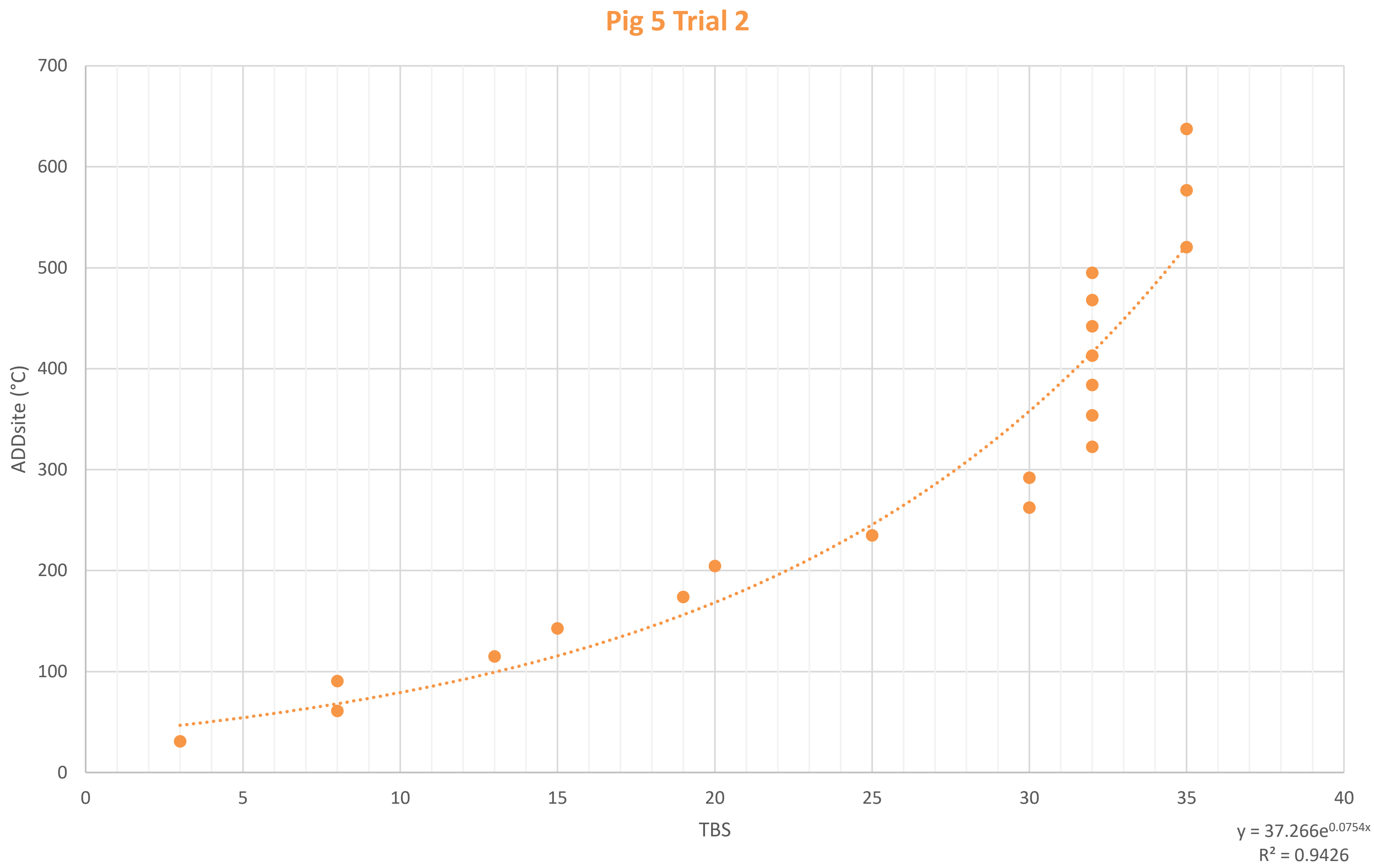

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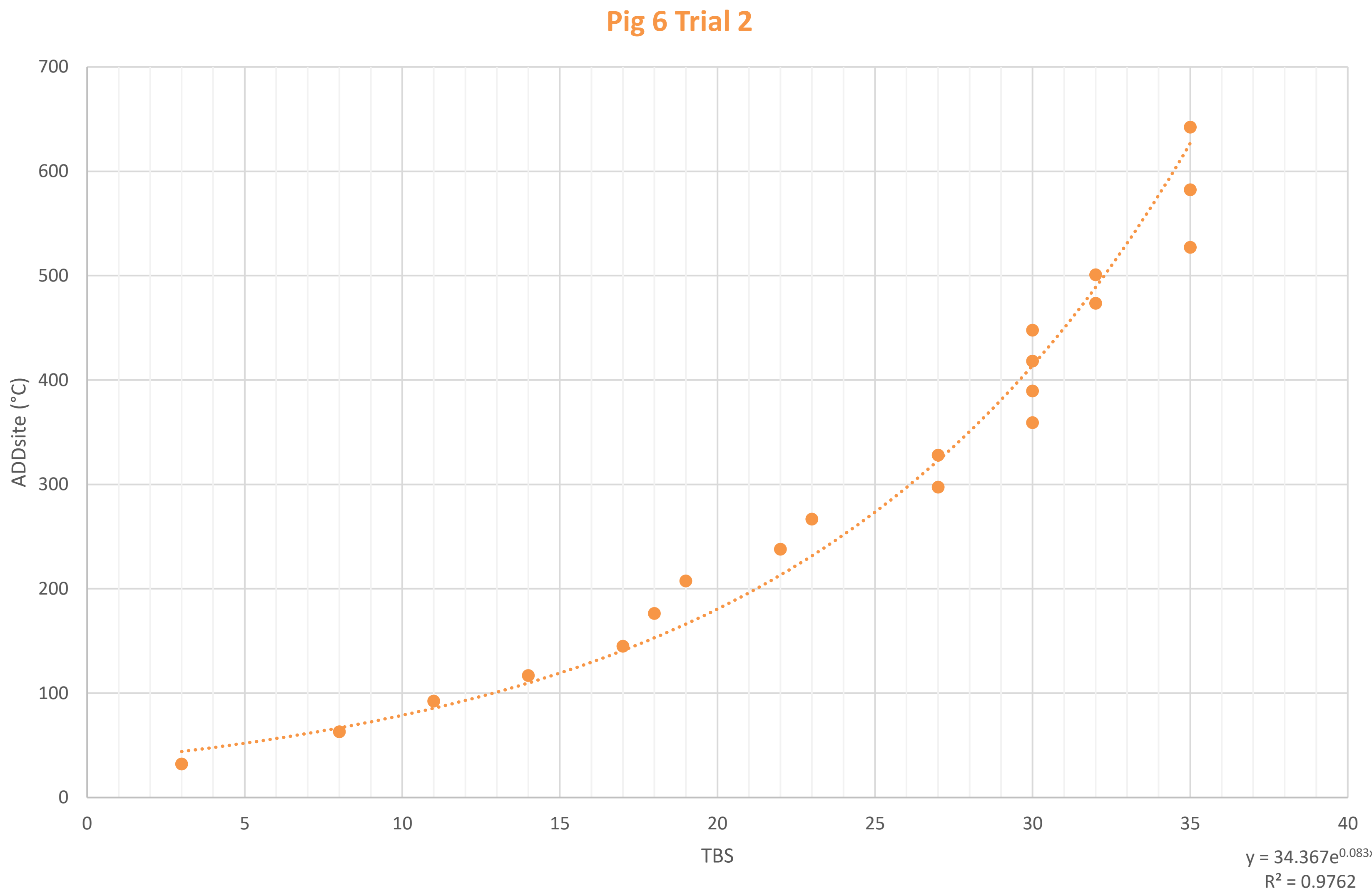

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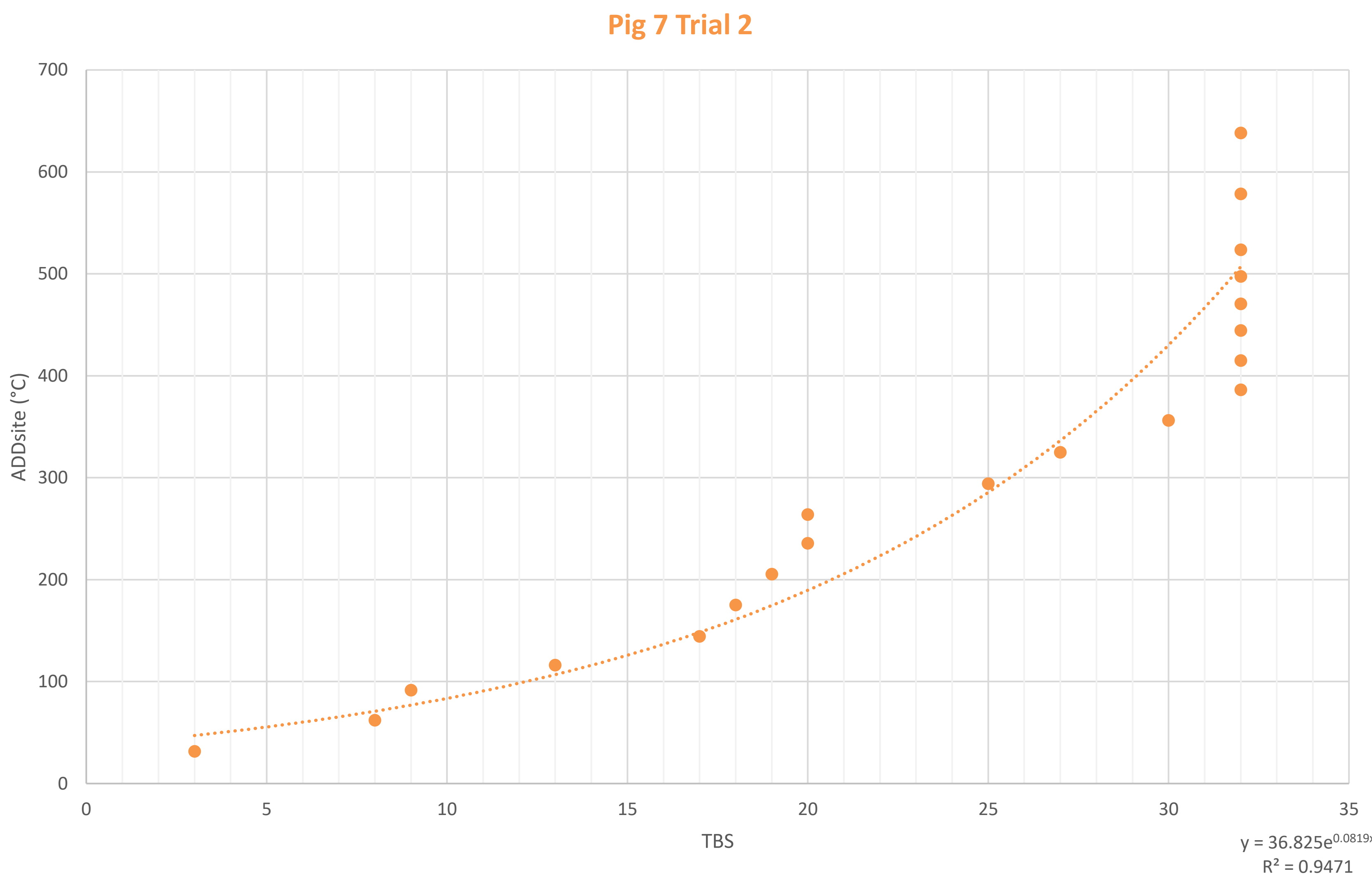

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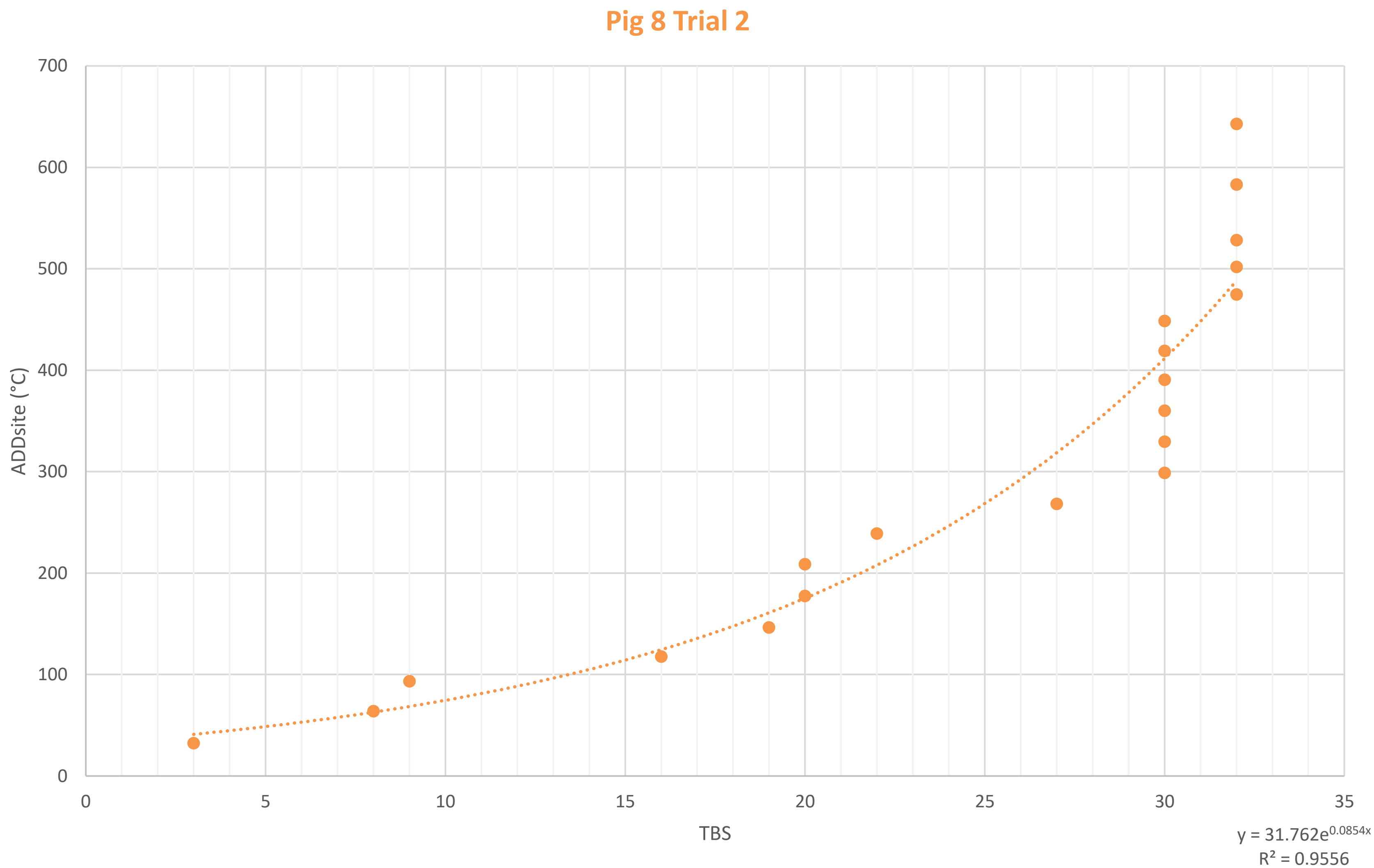

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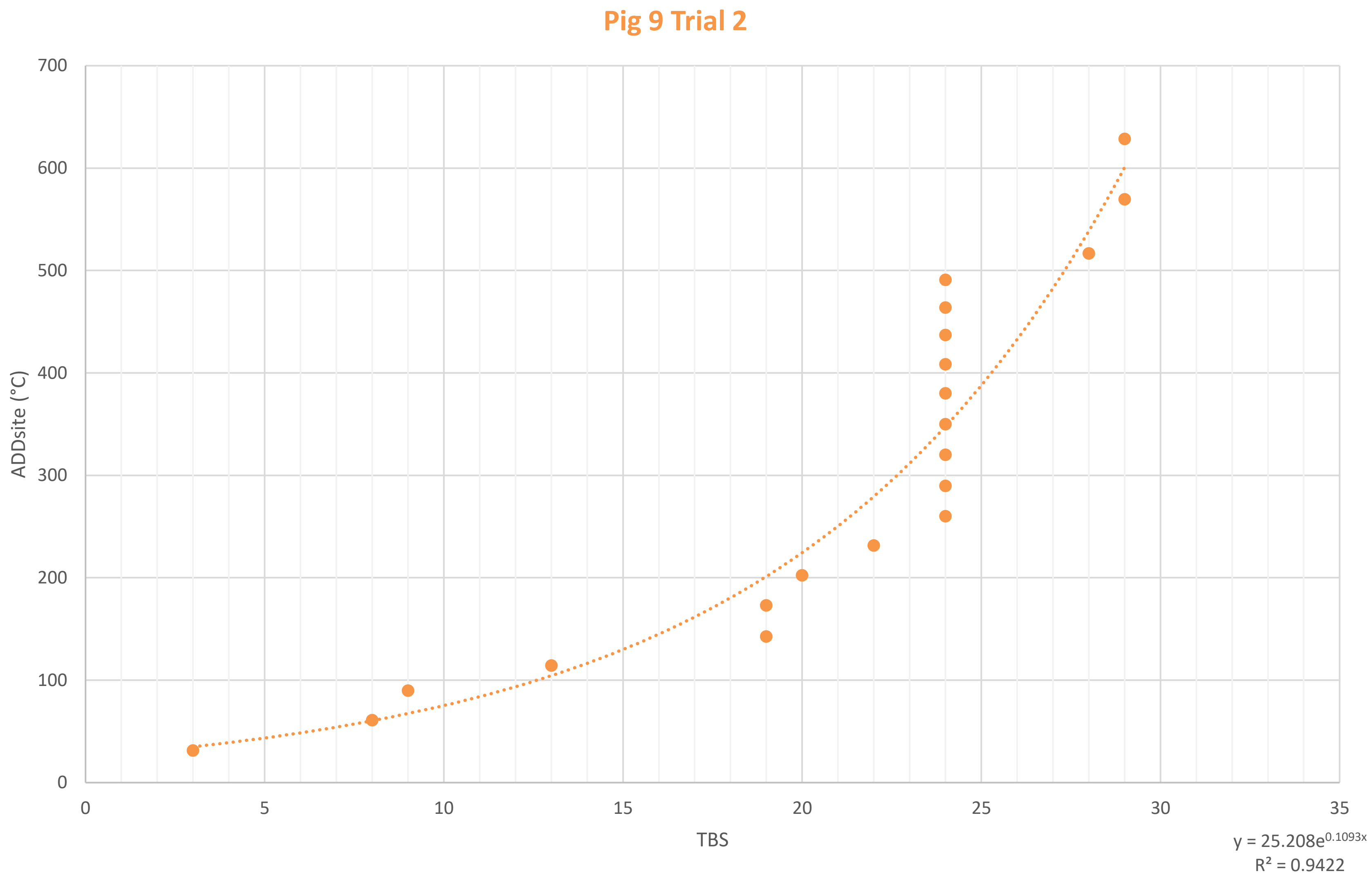

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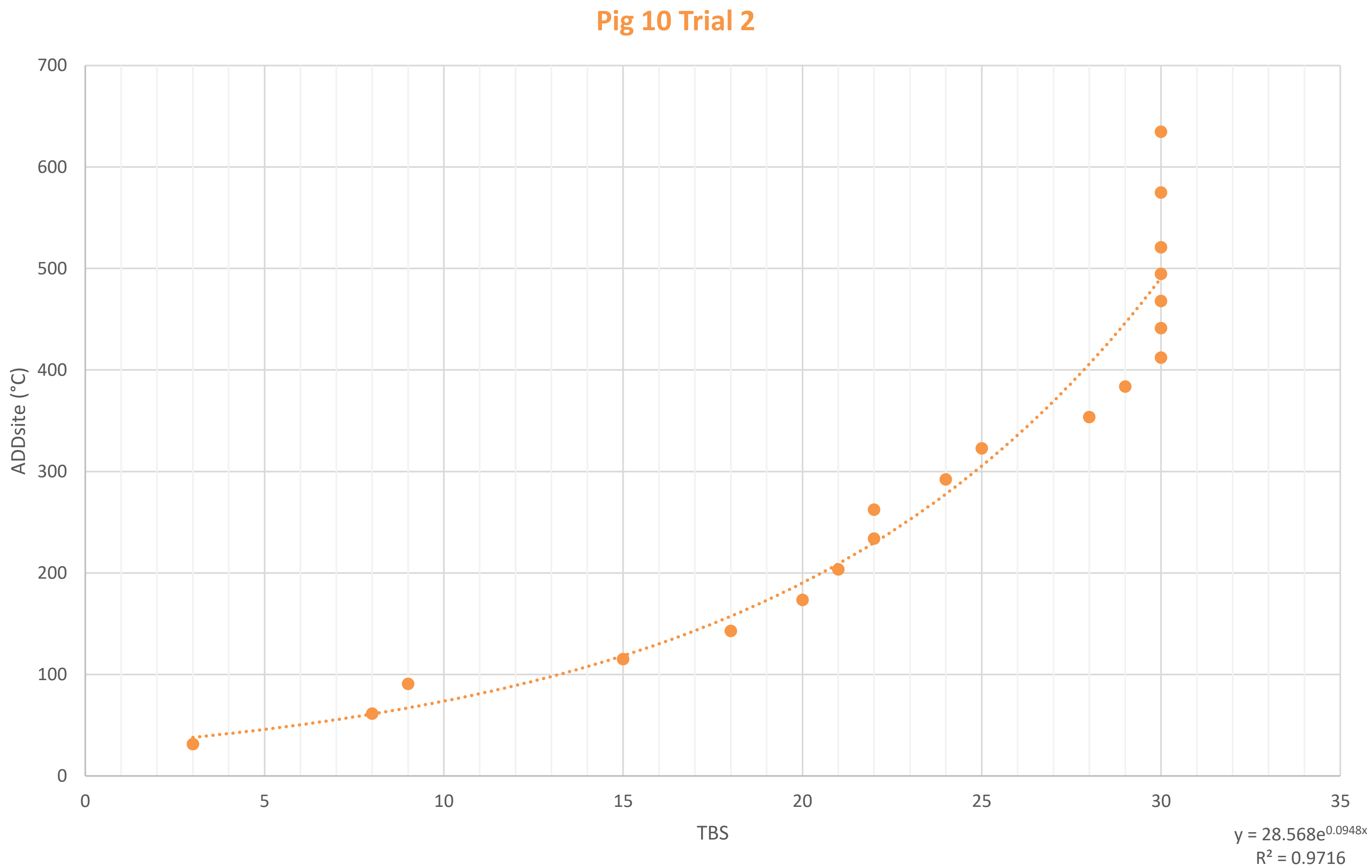

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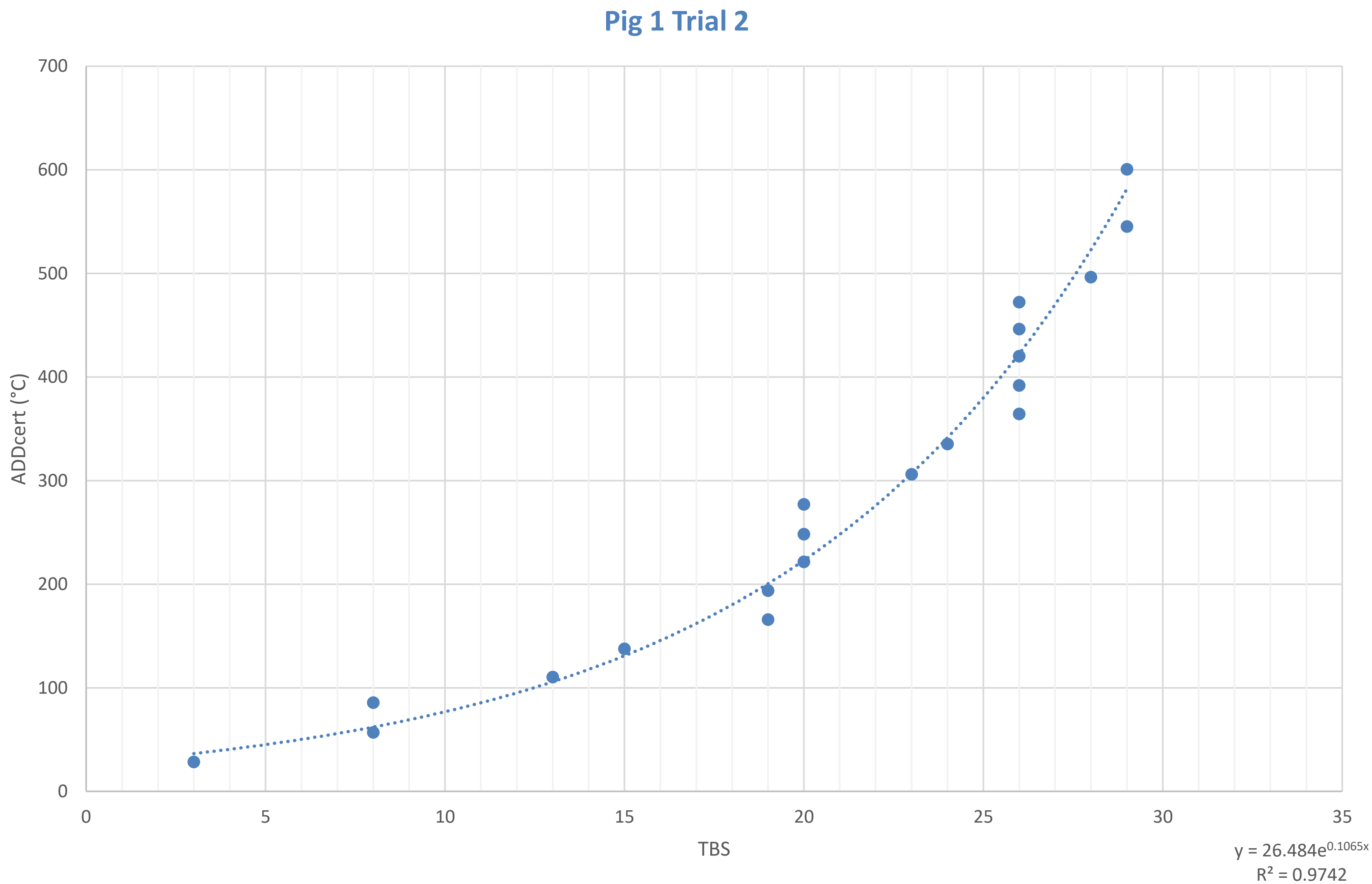

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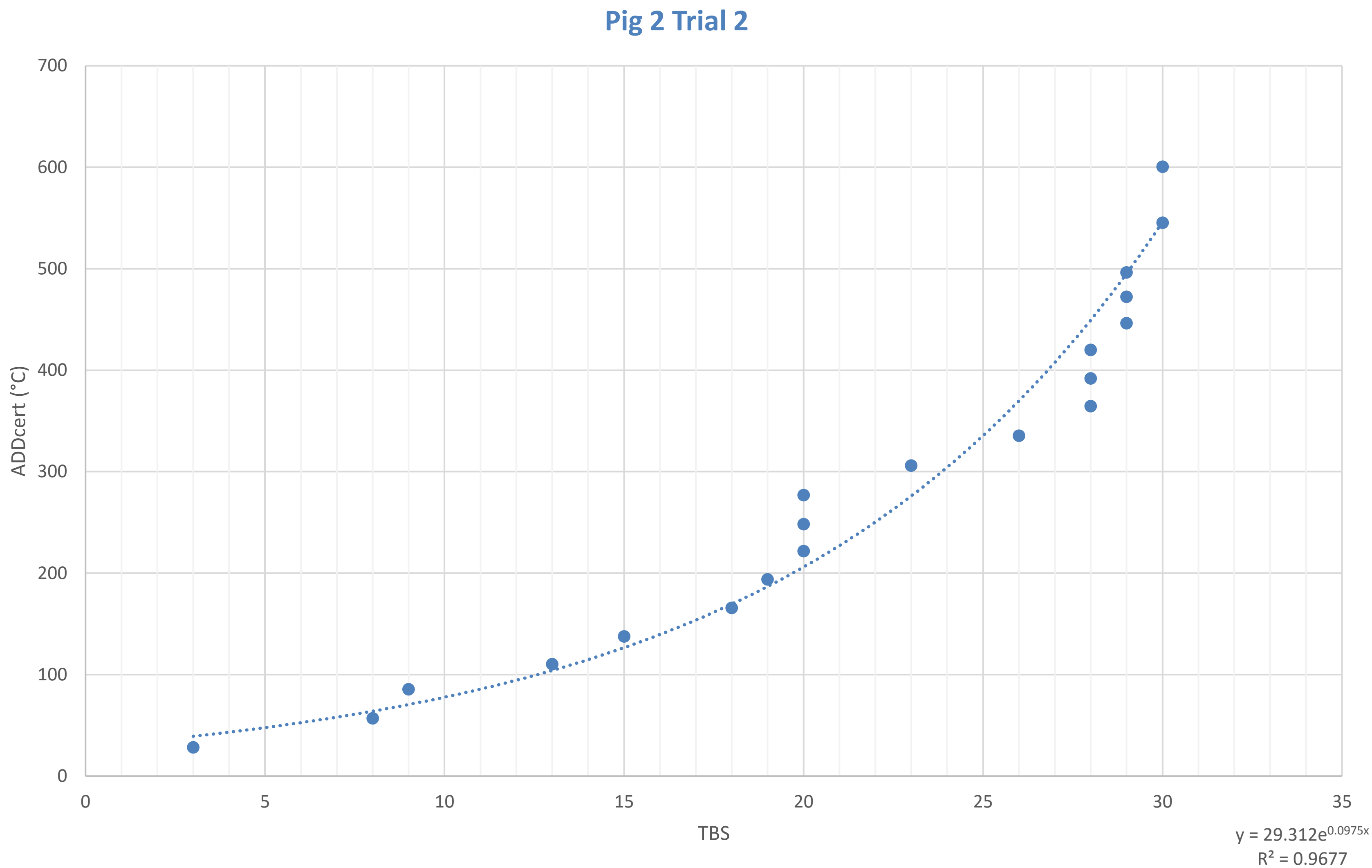

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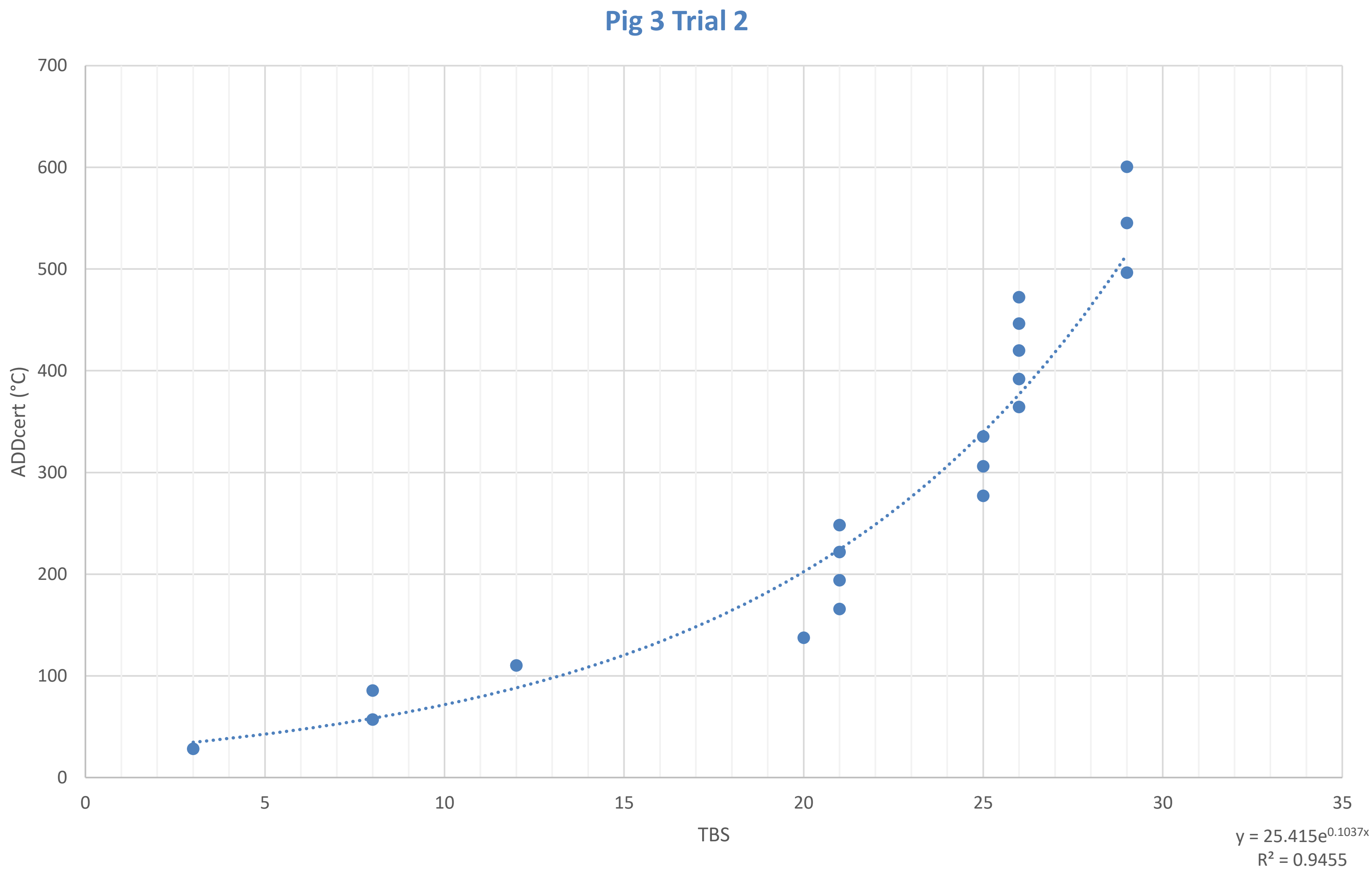

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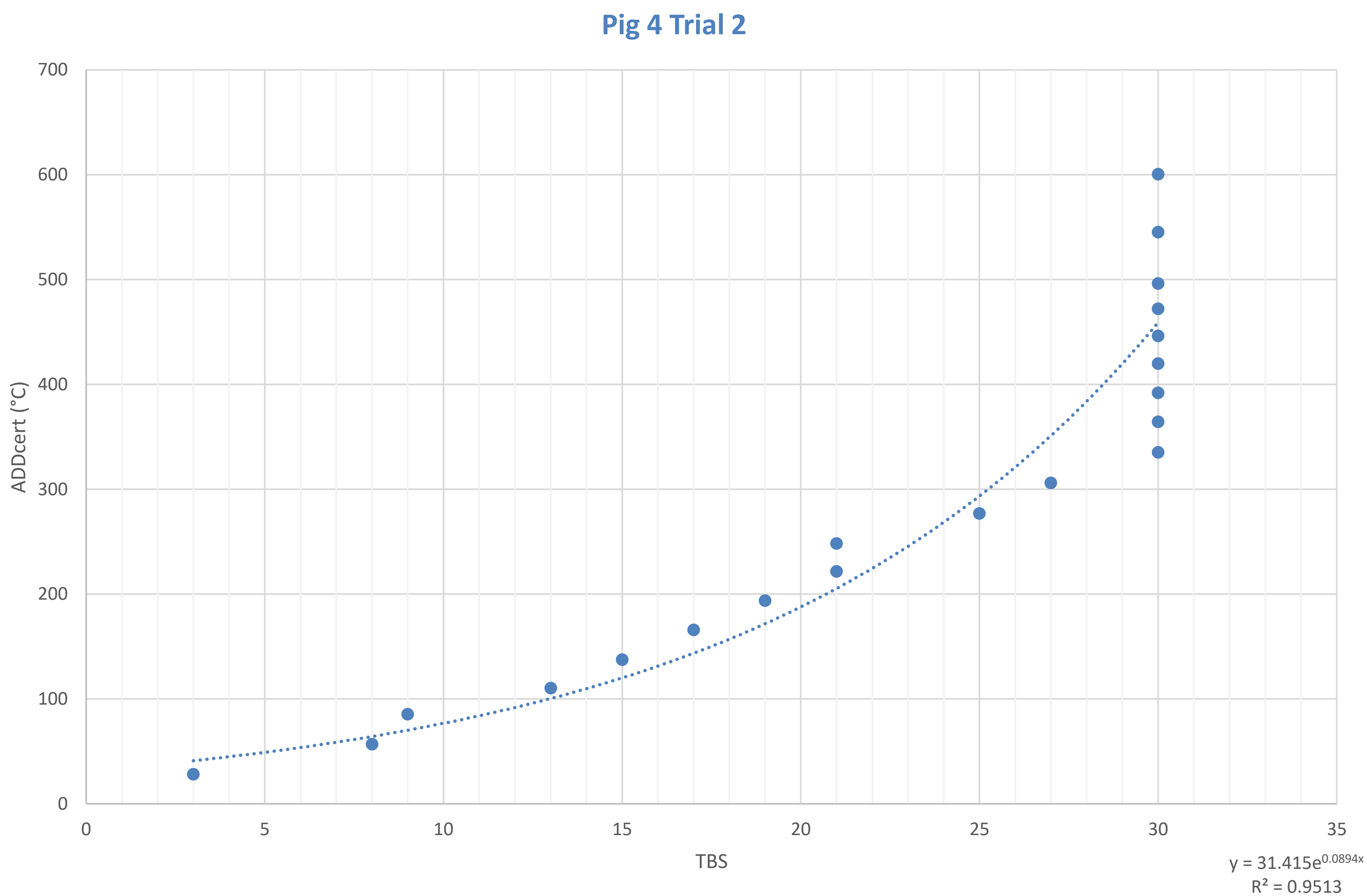

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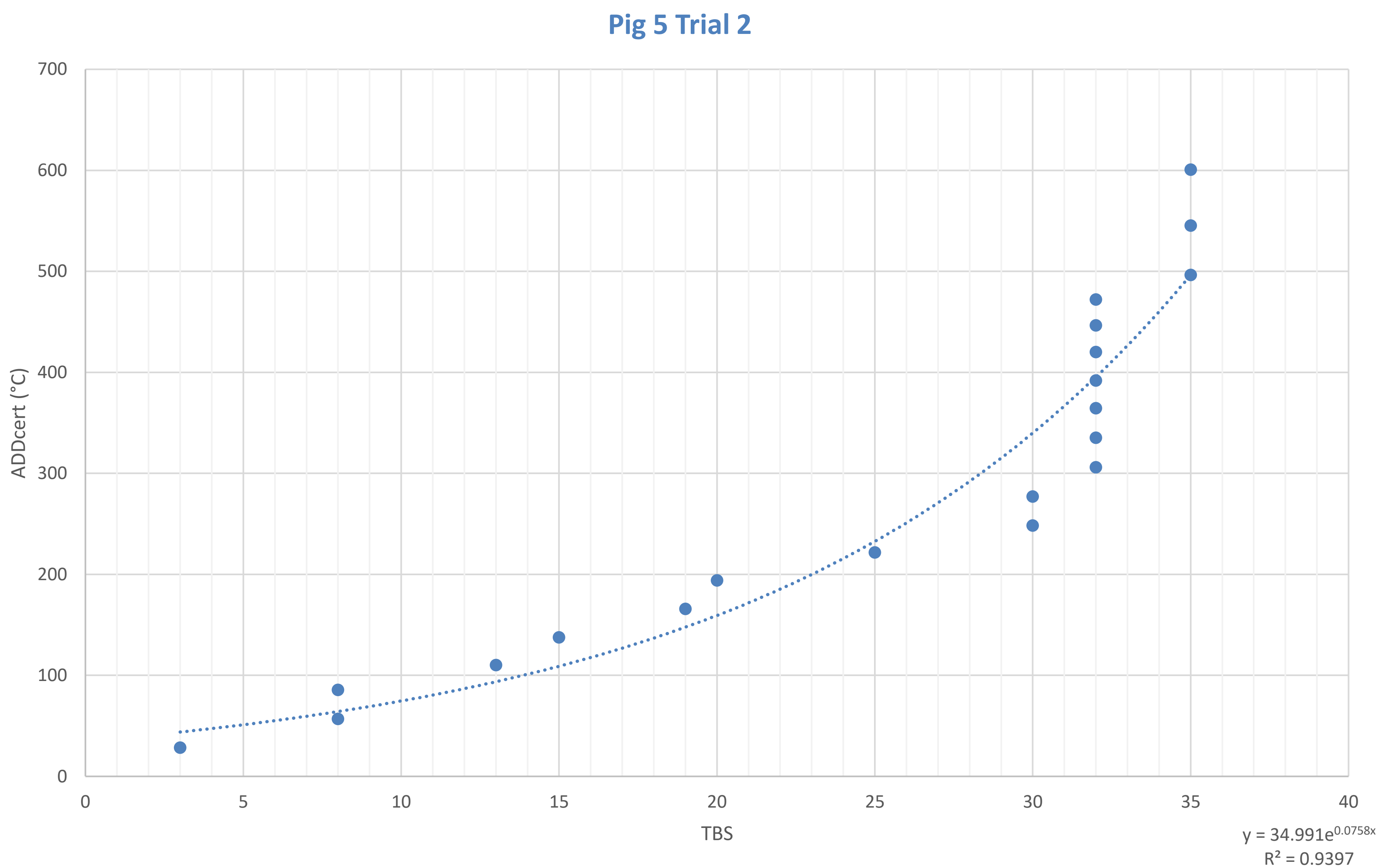

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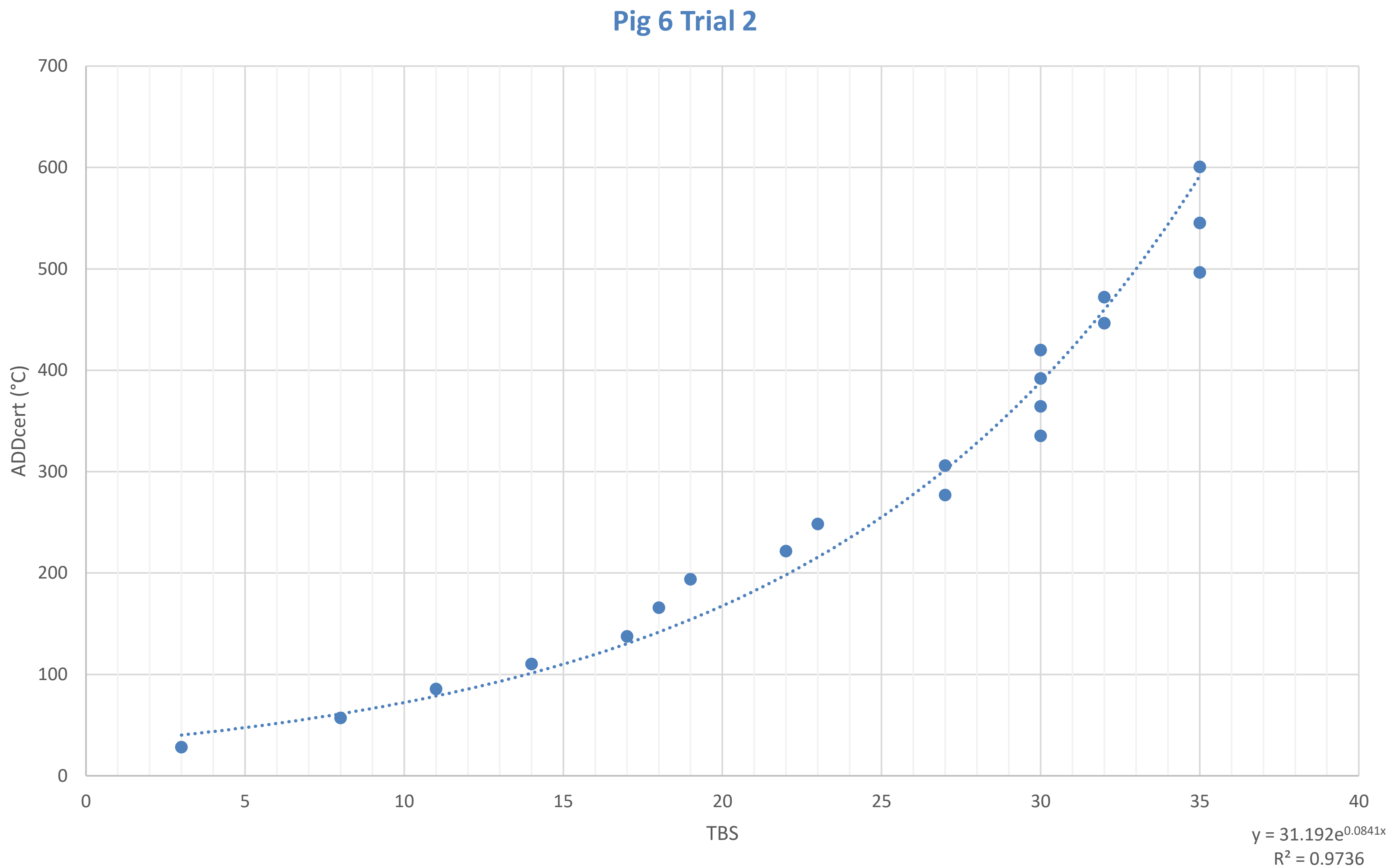

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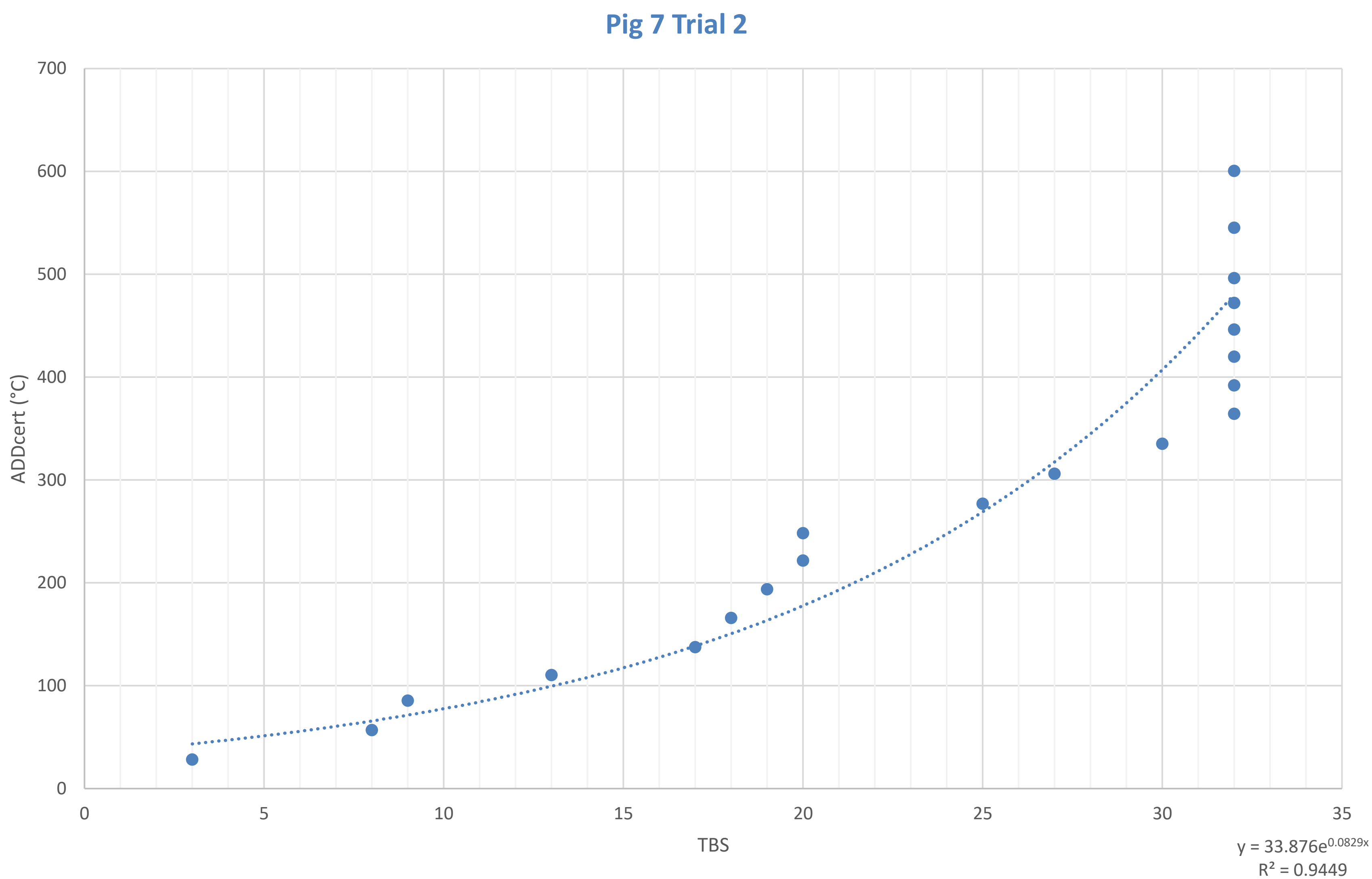

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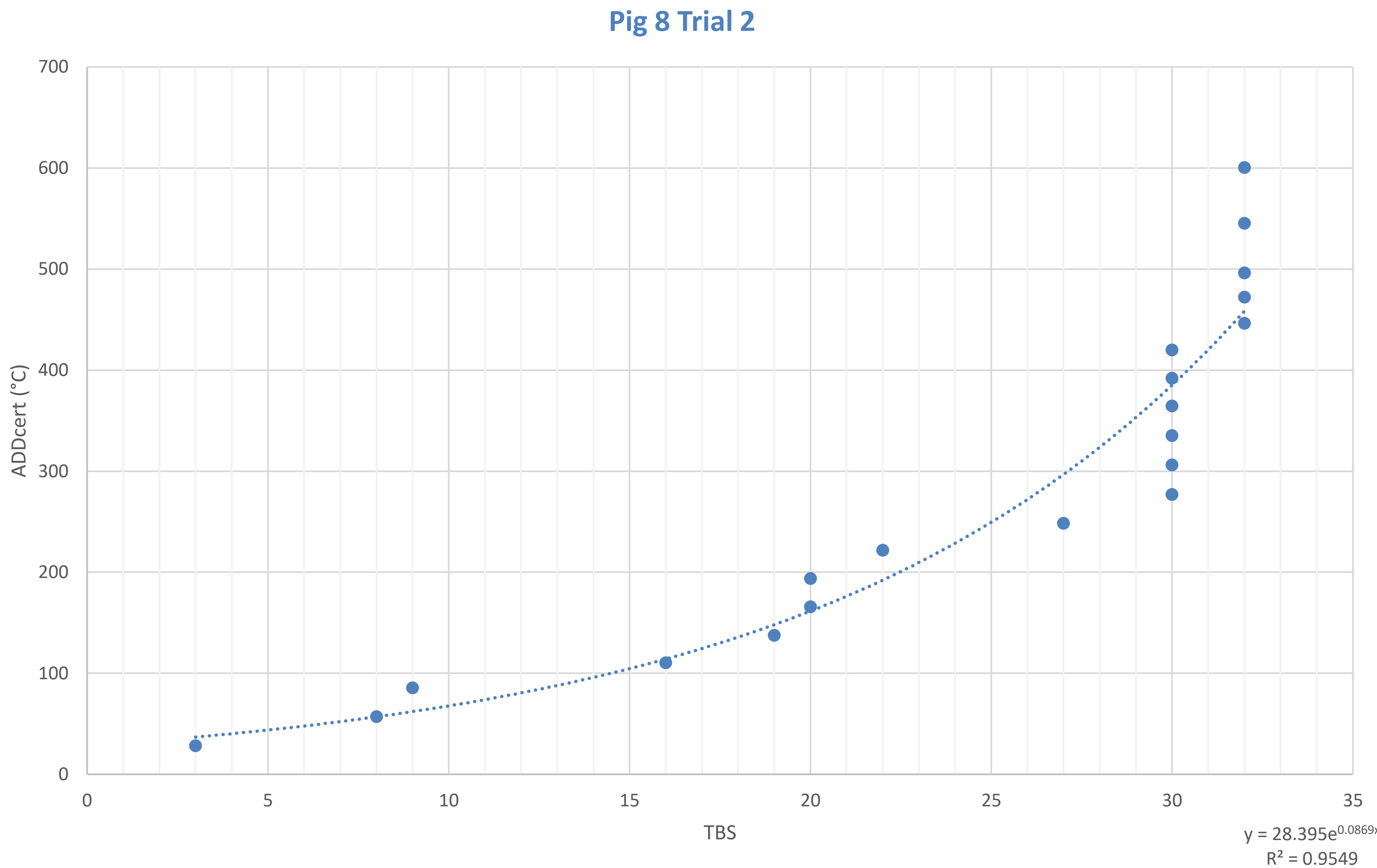

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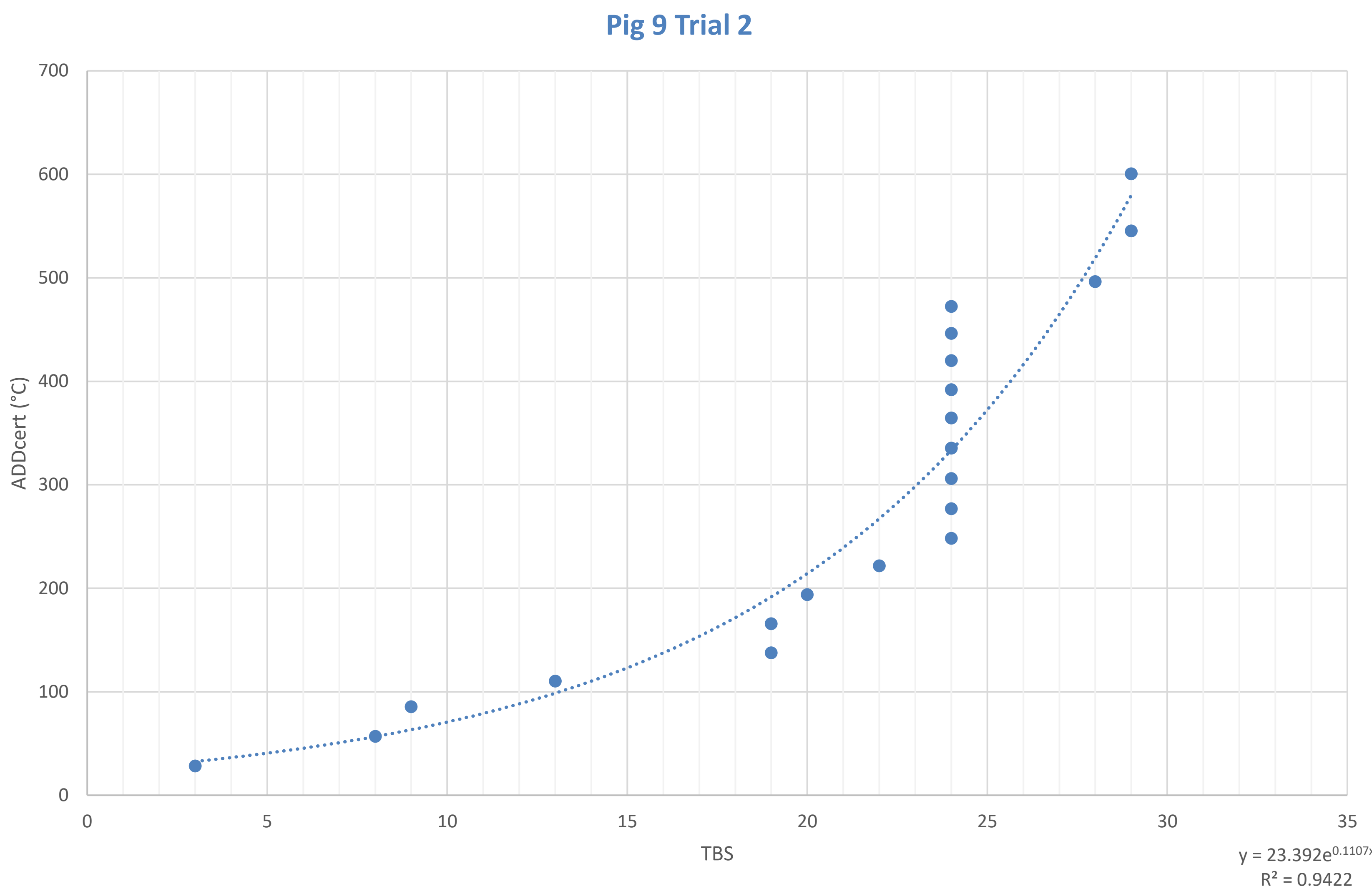

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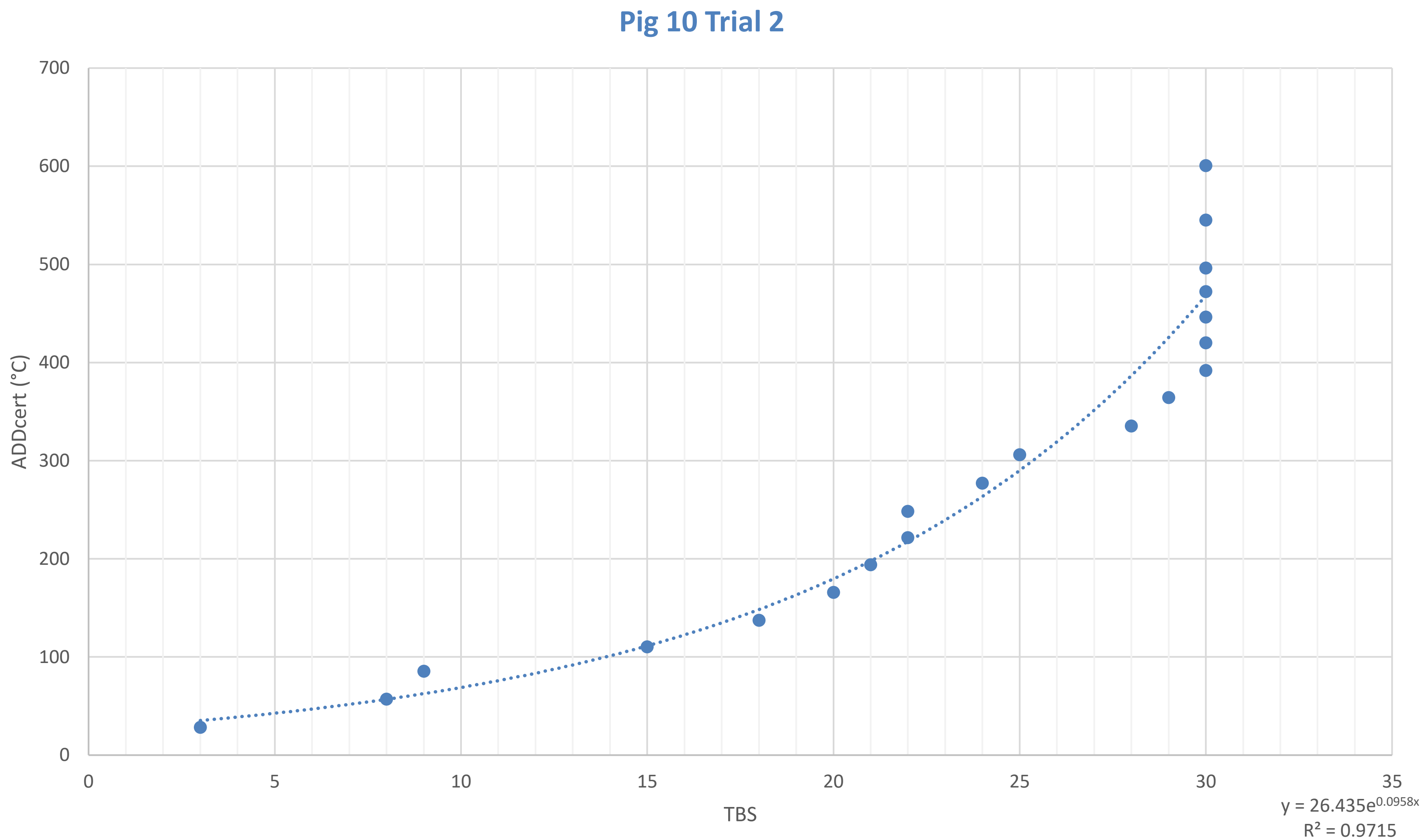

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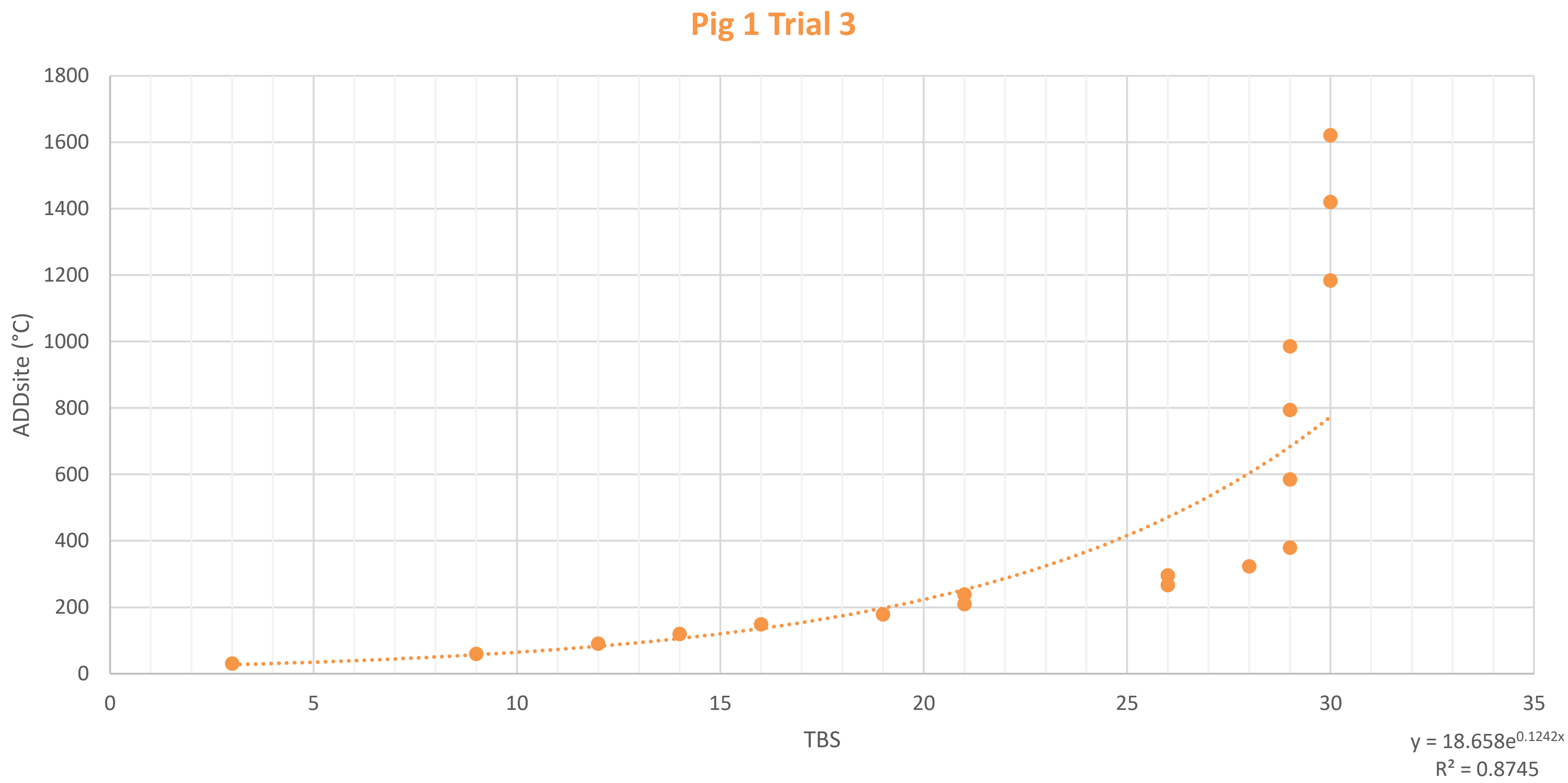
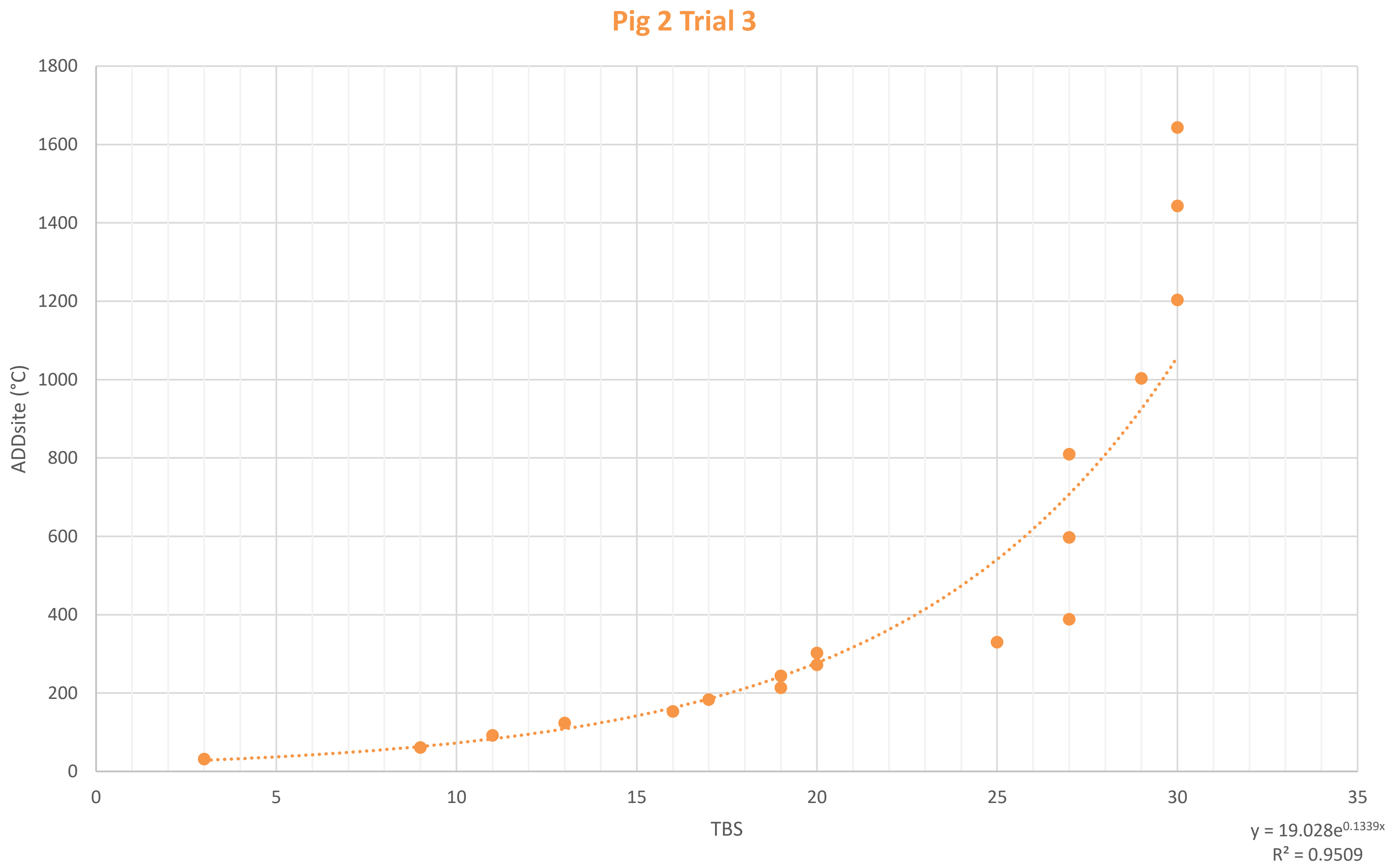


A

Figure B-21. Charts showing relationship between total body score and accumulated degree days for individual specimens in trial three. A) Pig 1 research site temperatures, B) Pig 2 research site temperatures, C) Pig 3 research site temperatures, D) Pig 4 research site temperatures, E) Pig 5 research site temperatures, F) Pig 6 research site temperatures, G) Pig 7 research site temperatures, H) Pig 8 research site temperatures, I) Pig 9 research site temperatures, J) Pig 10 research site temperatures, K) Pig 1 certified temperatures, L) Pig 2 certified temperatures, M) Pig 3 certified temperatures, N) Pig 4 certified temperatures, O) Pig 5 certified temperatures, P) Pig 6 certified temperatures, Q) Pig 7 certified temperatures, R) Pig 8 certified temperatures, S) Pig 9 certified temperatures, T) Pig 10 certified temperatures



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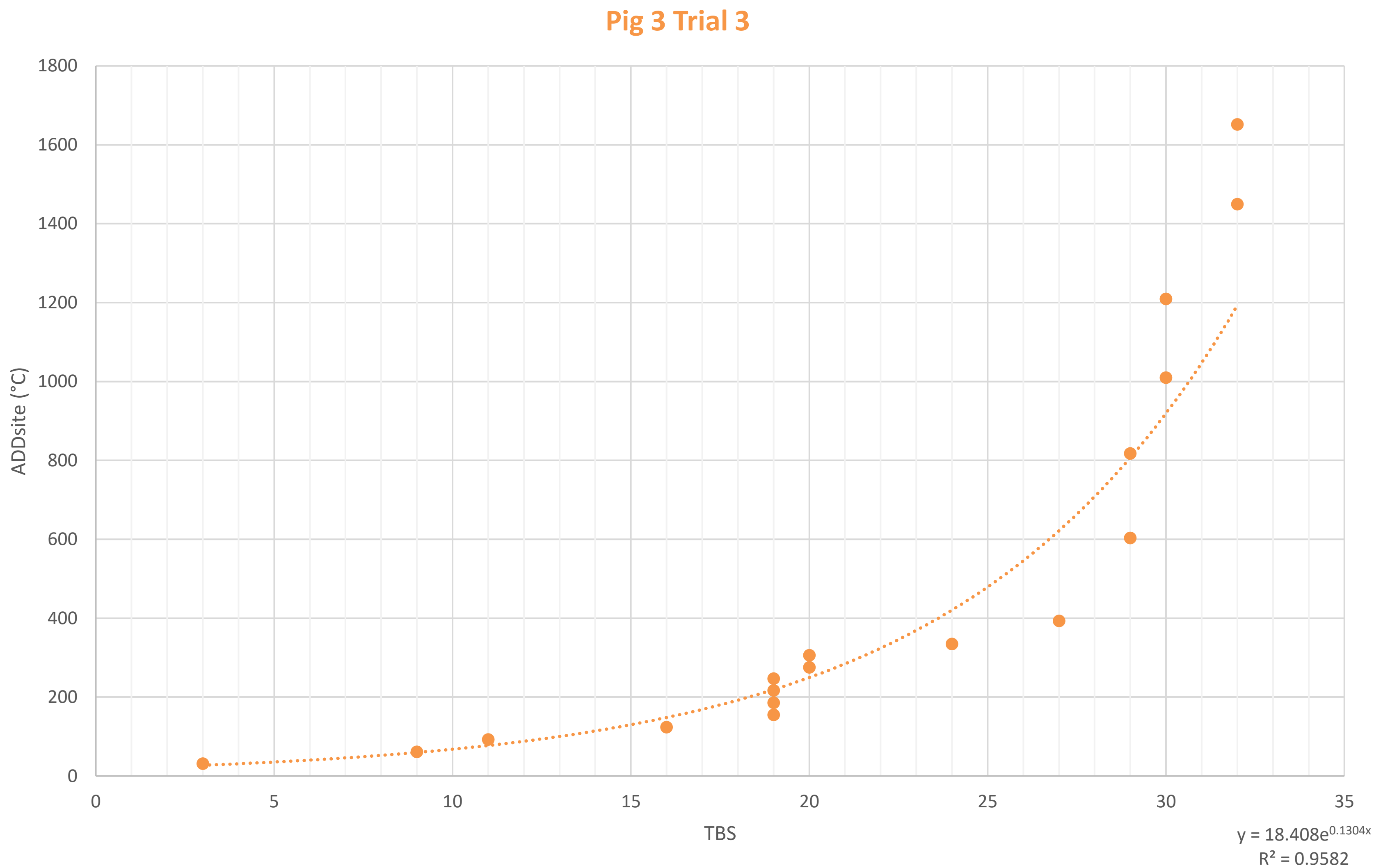

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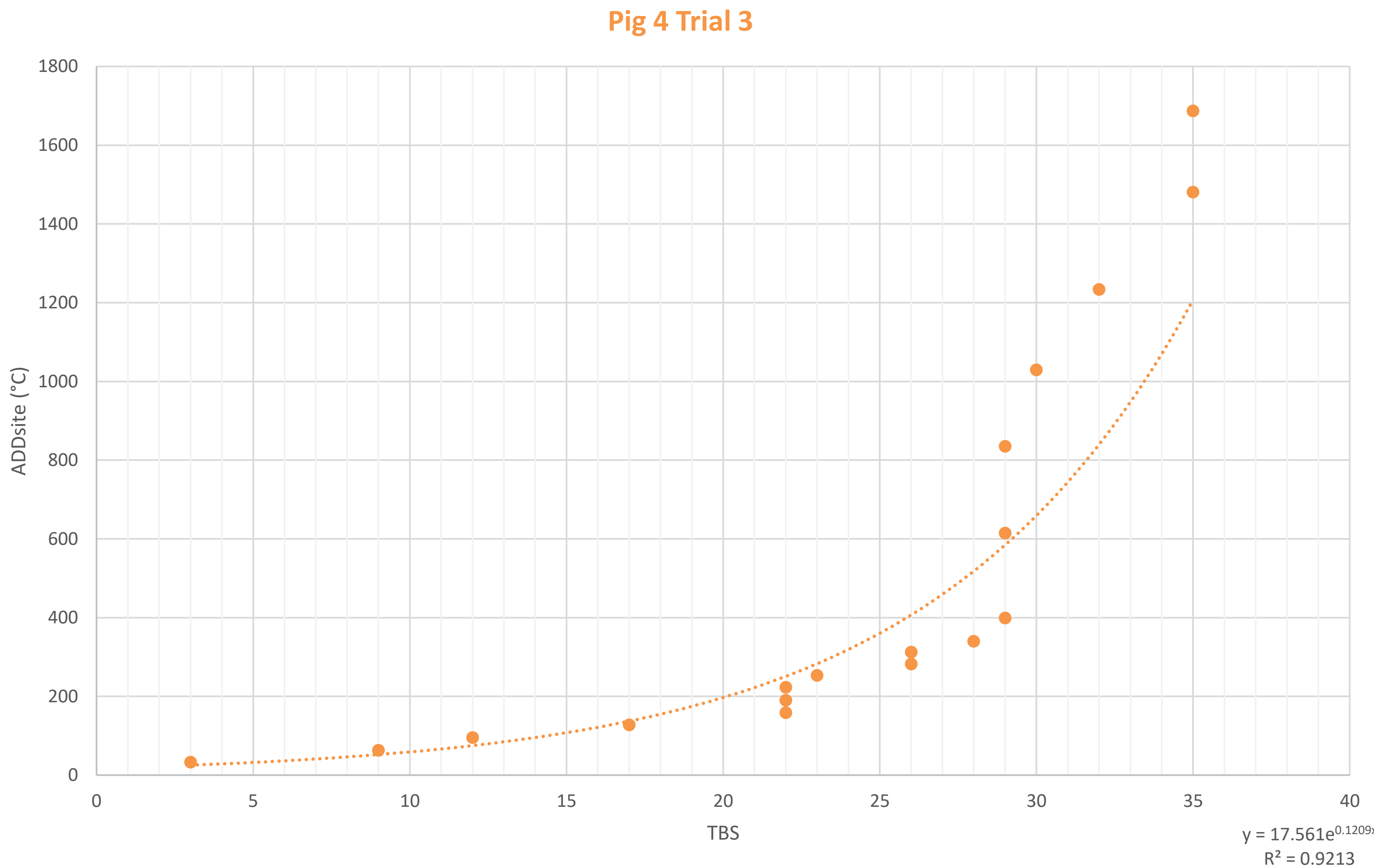

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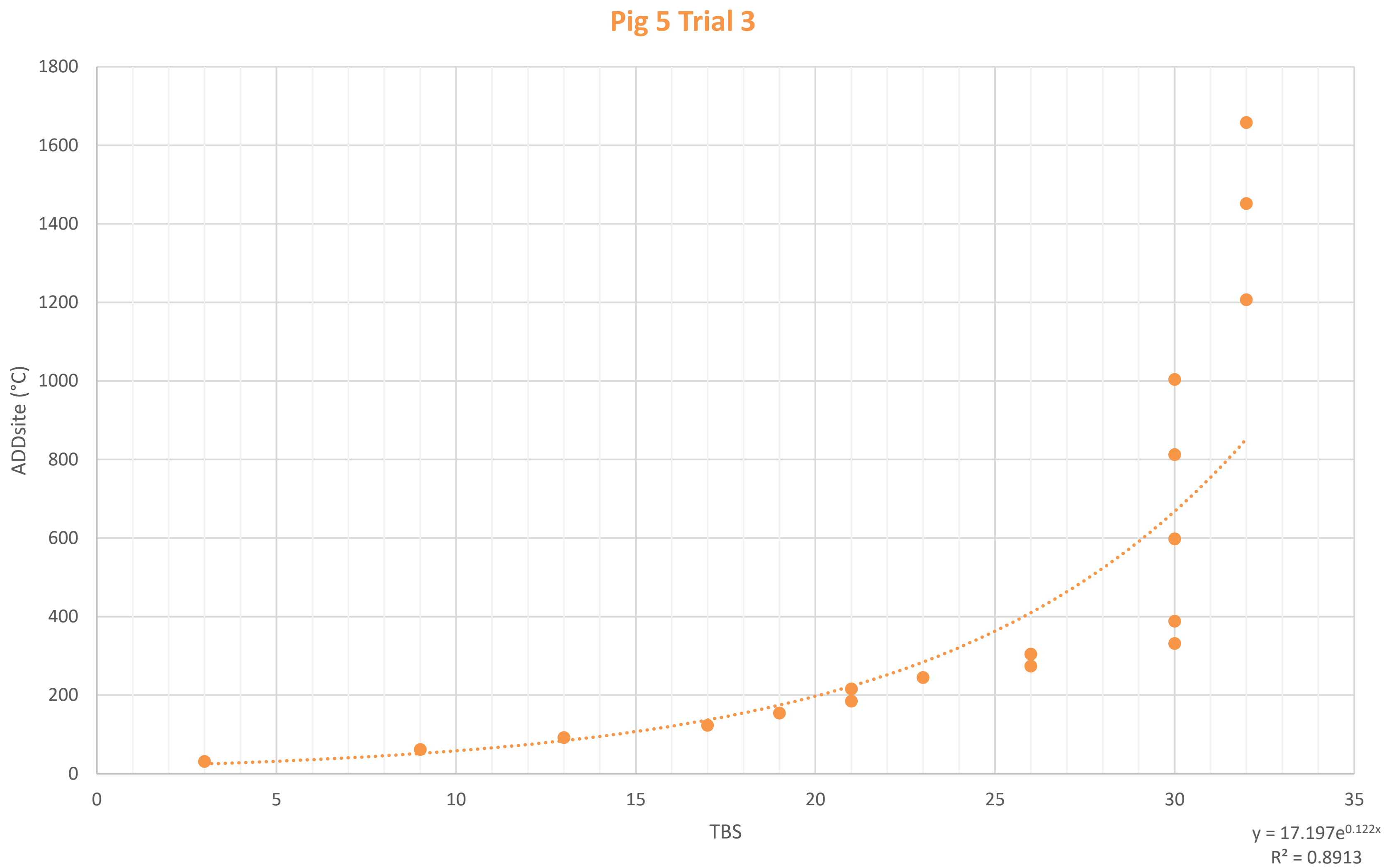

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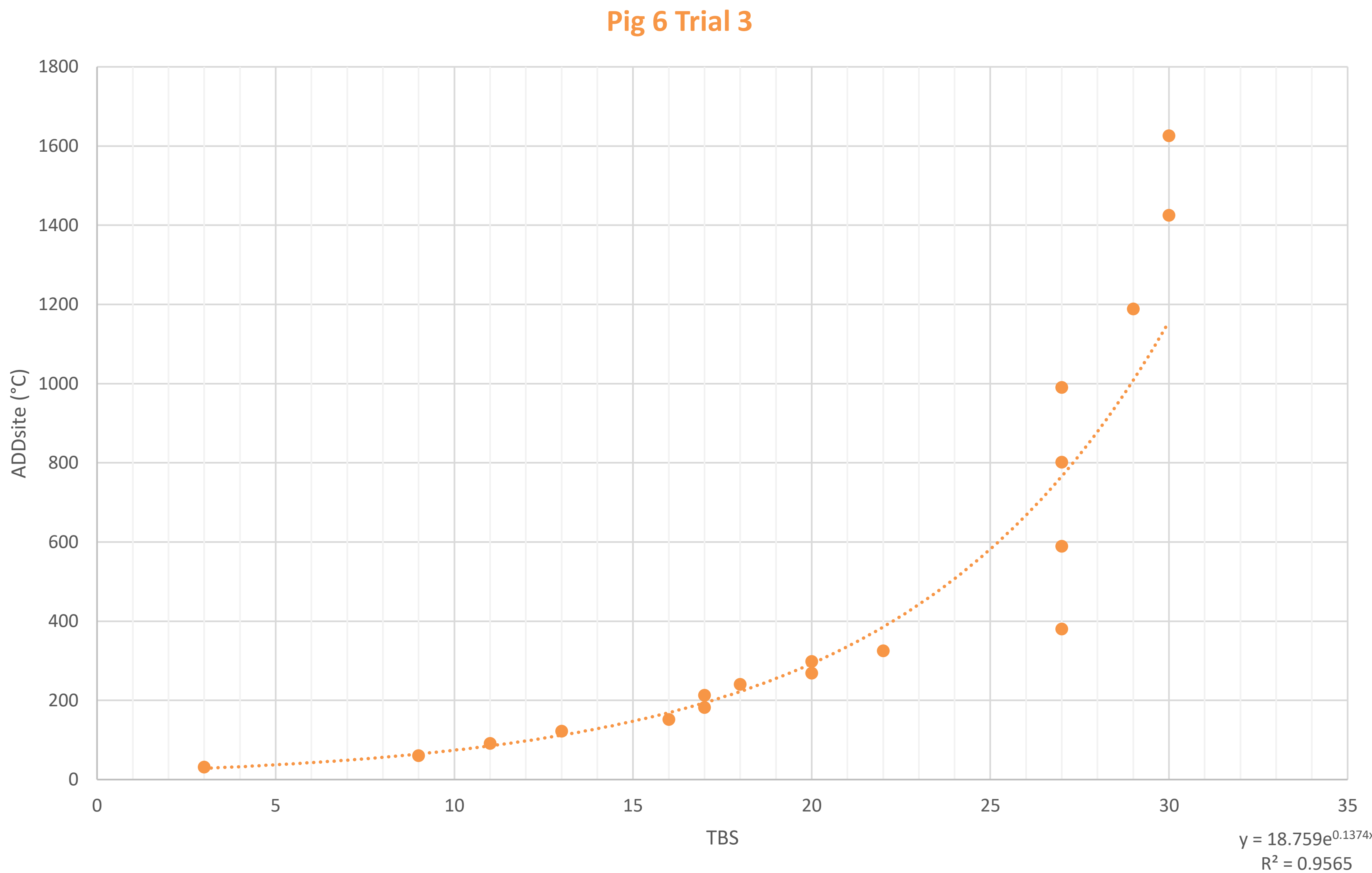

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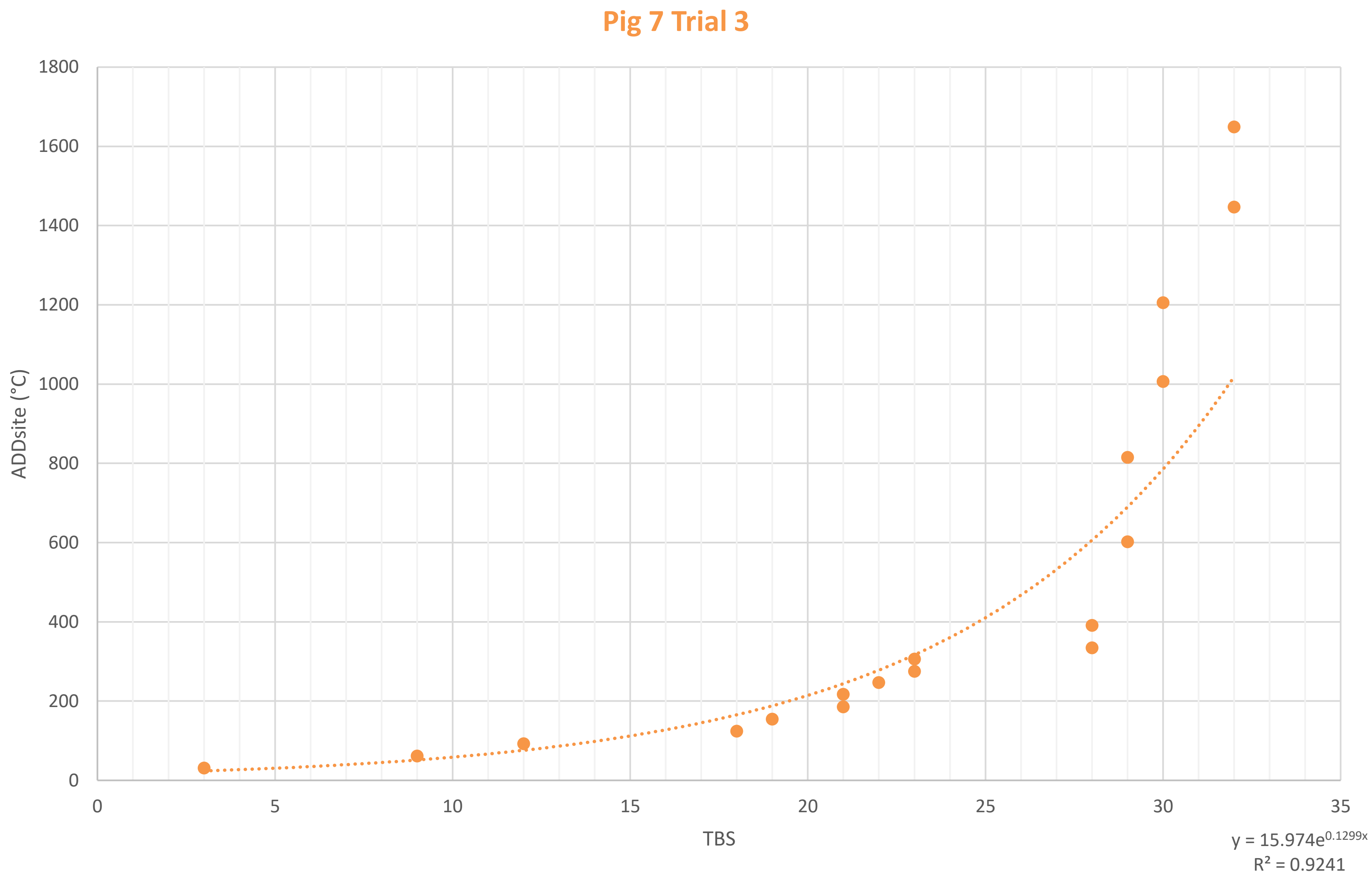

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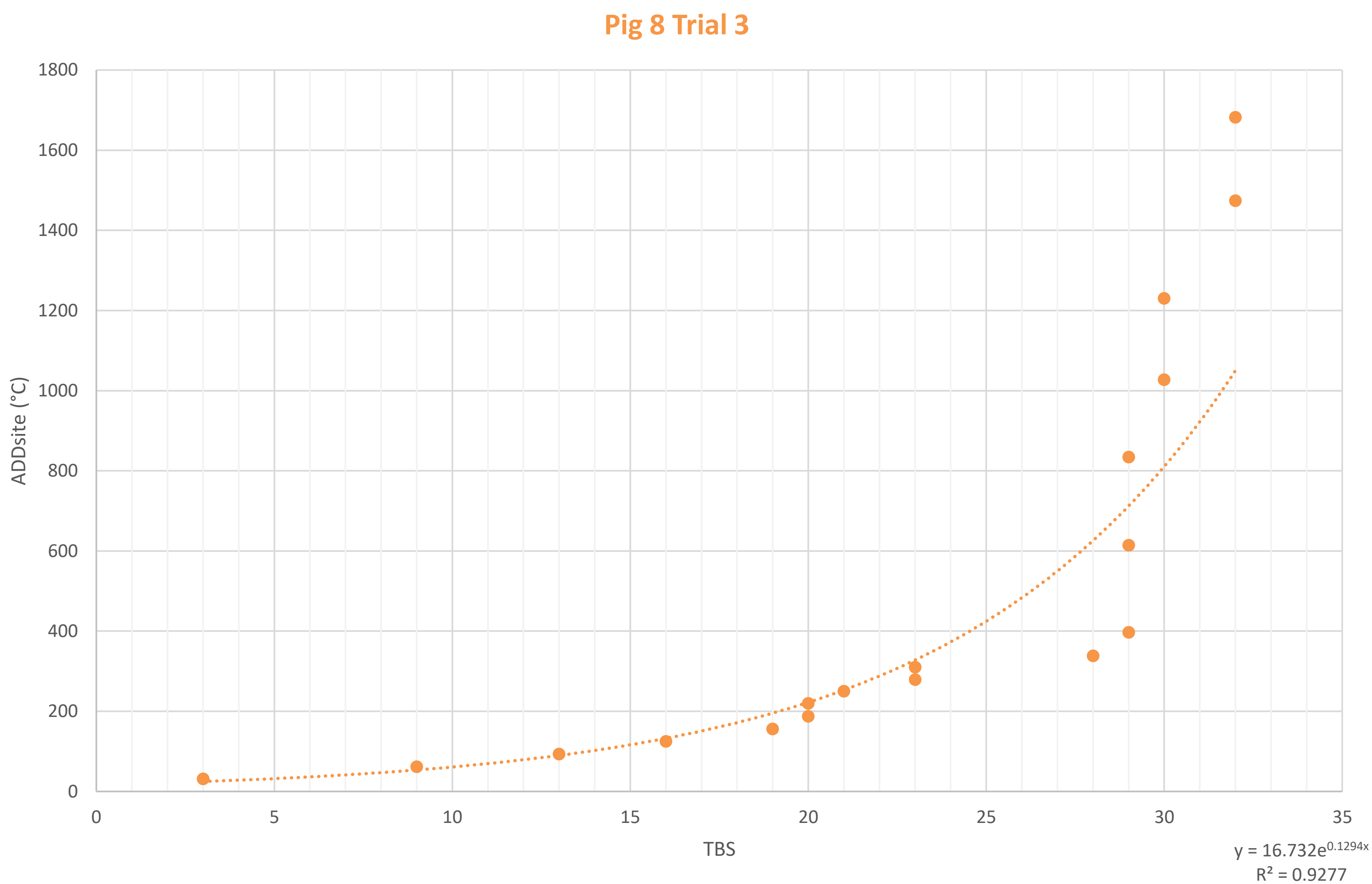

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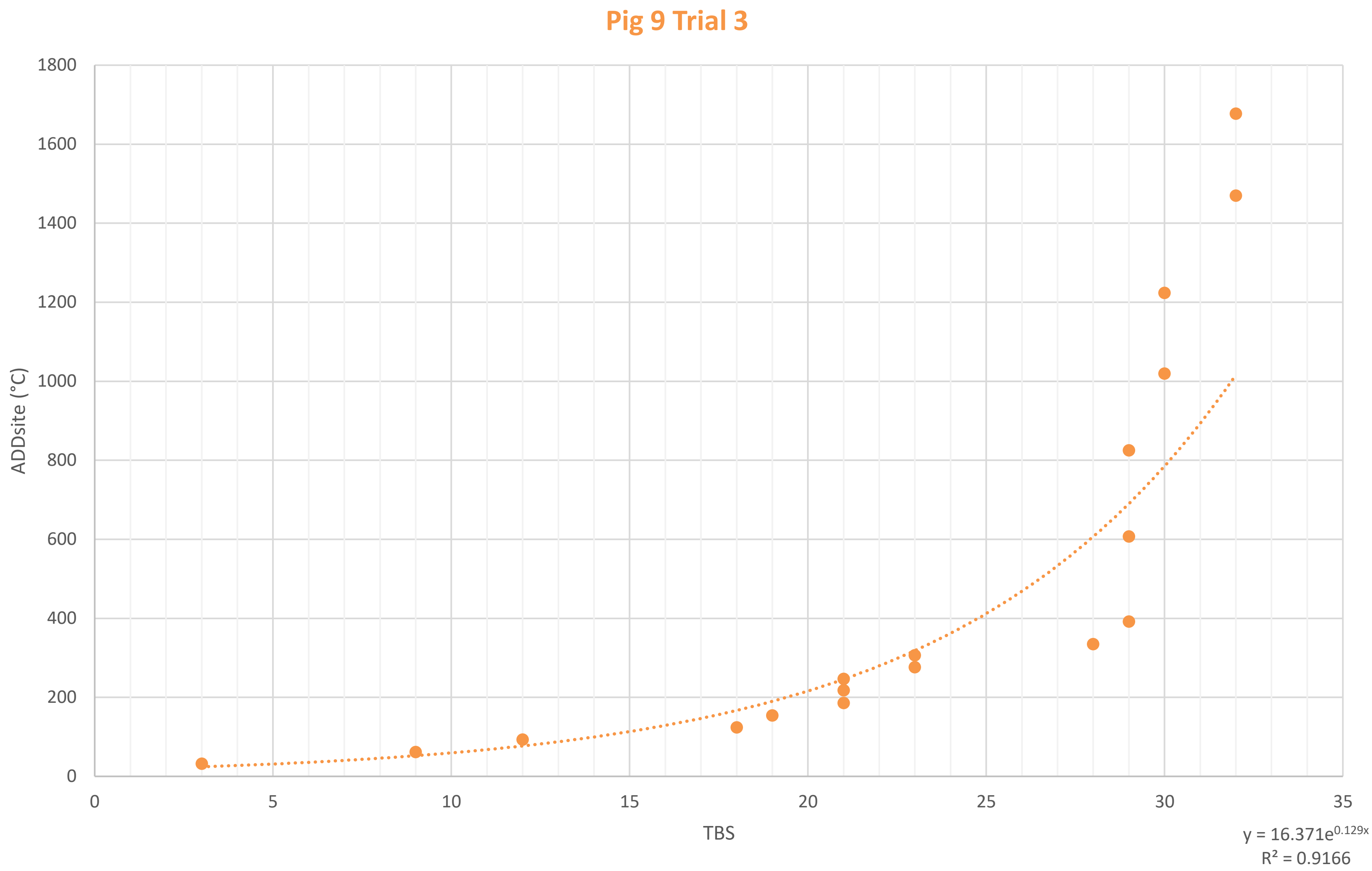

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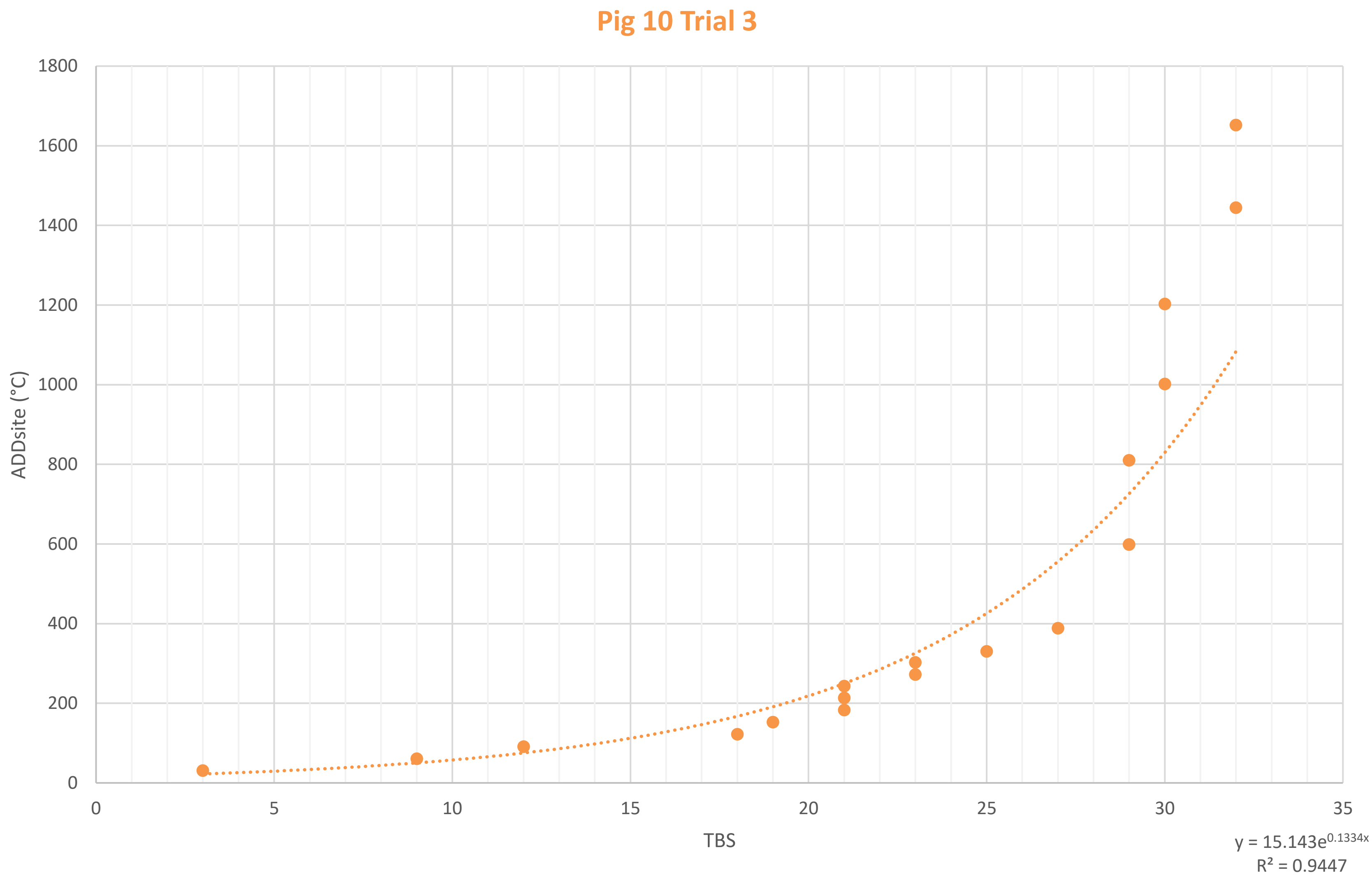

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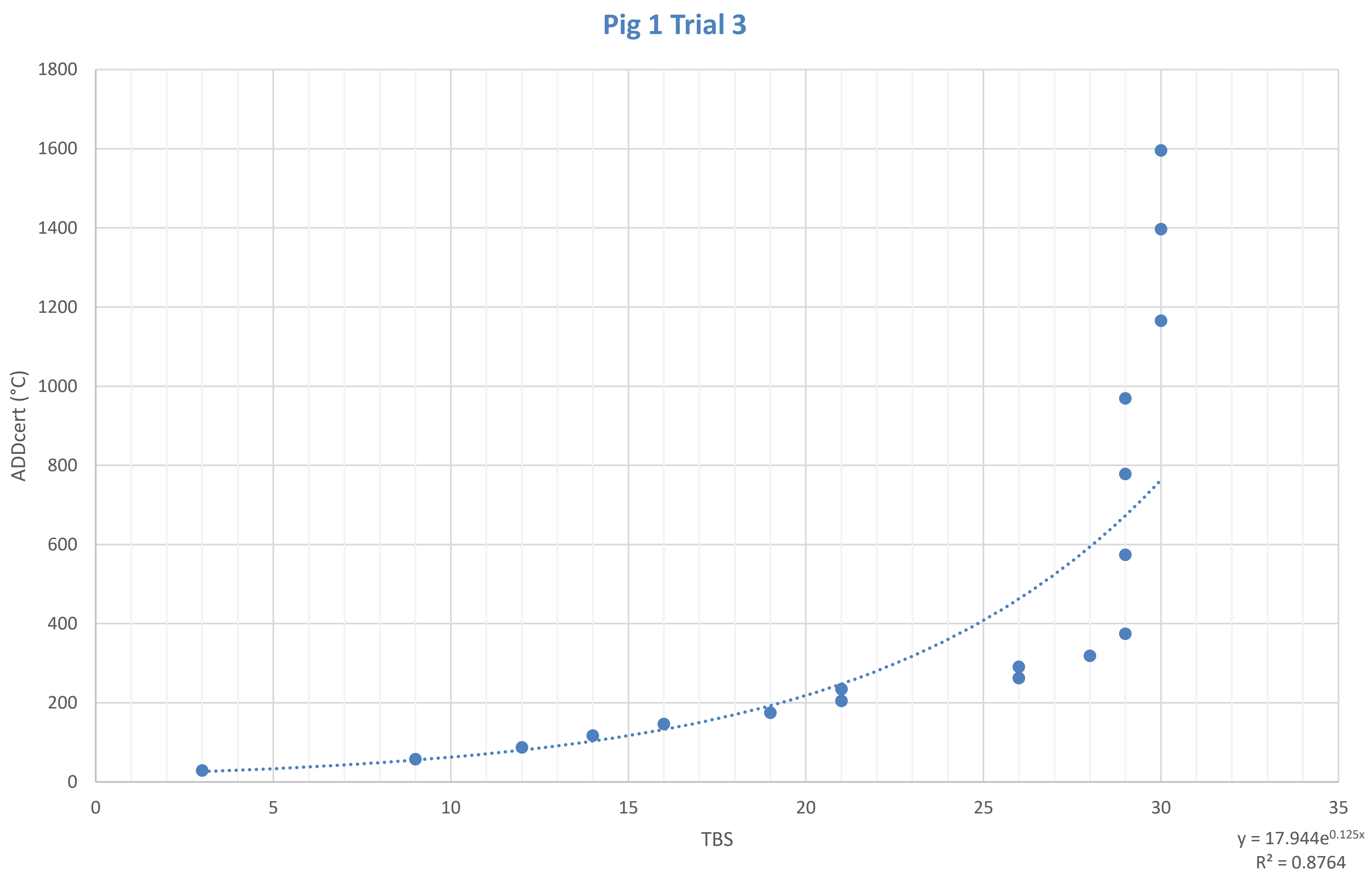

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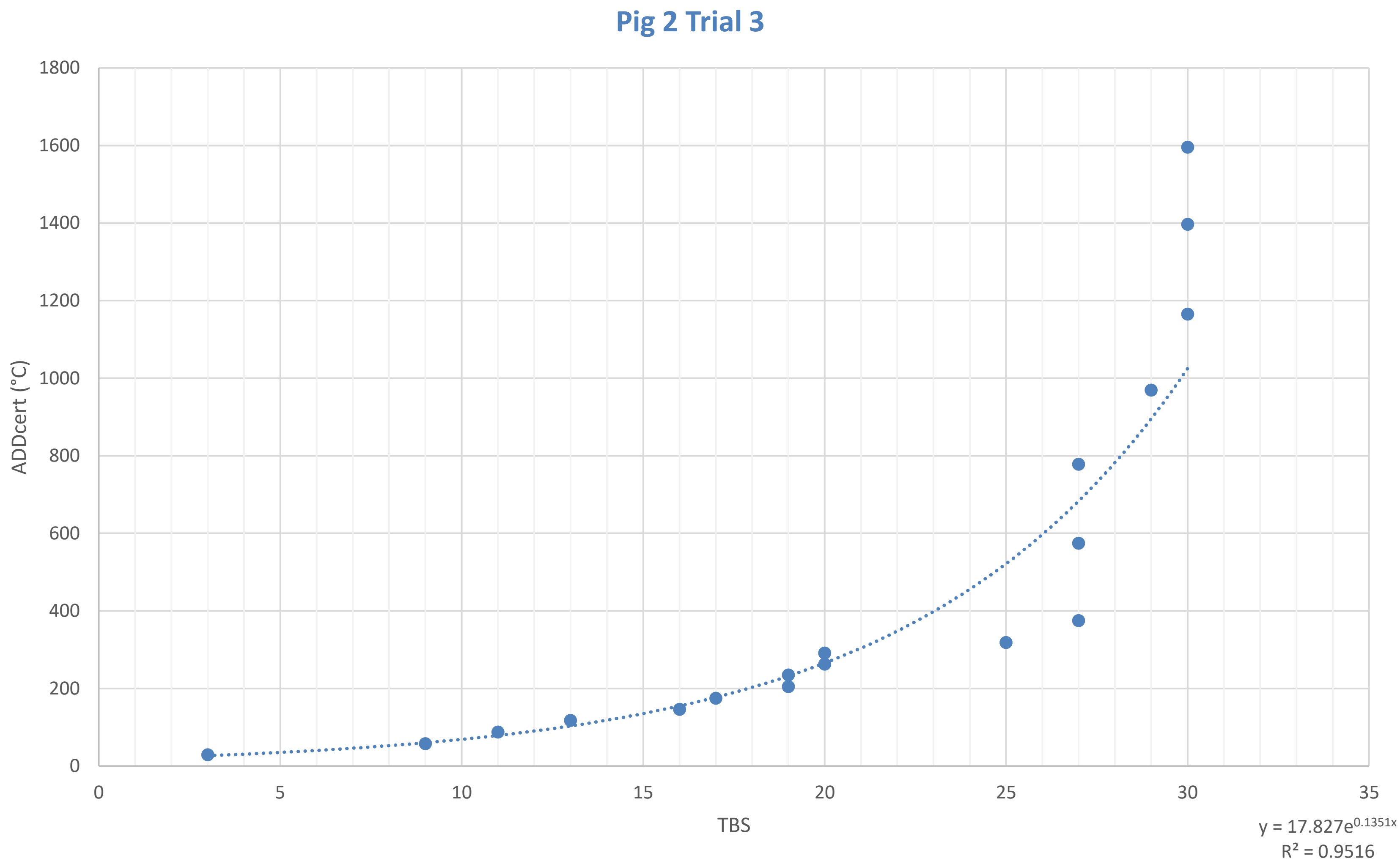

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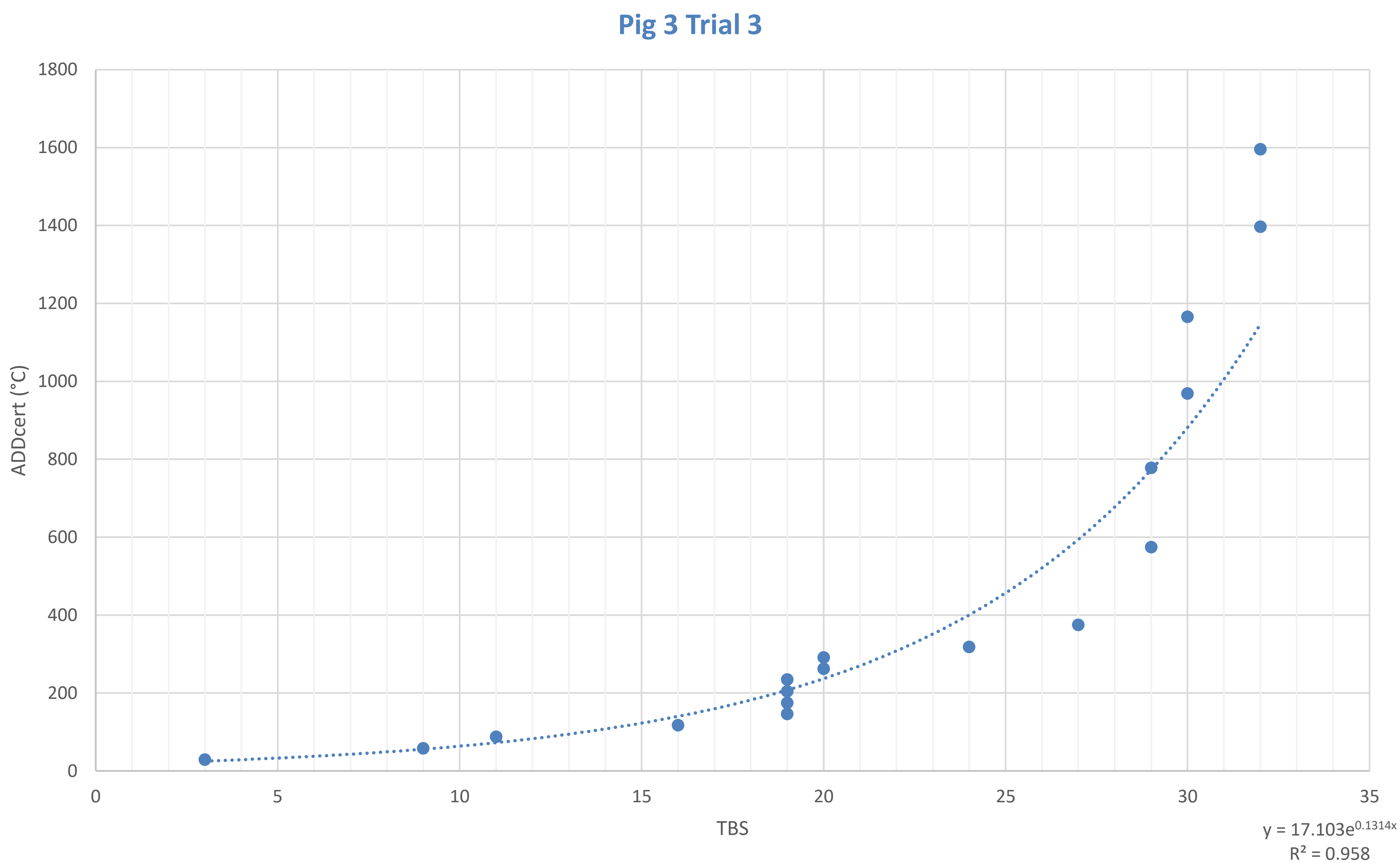

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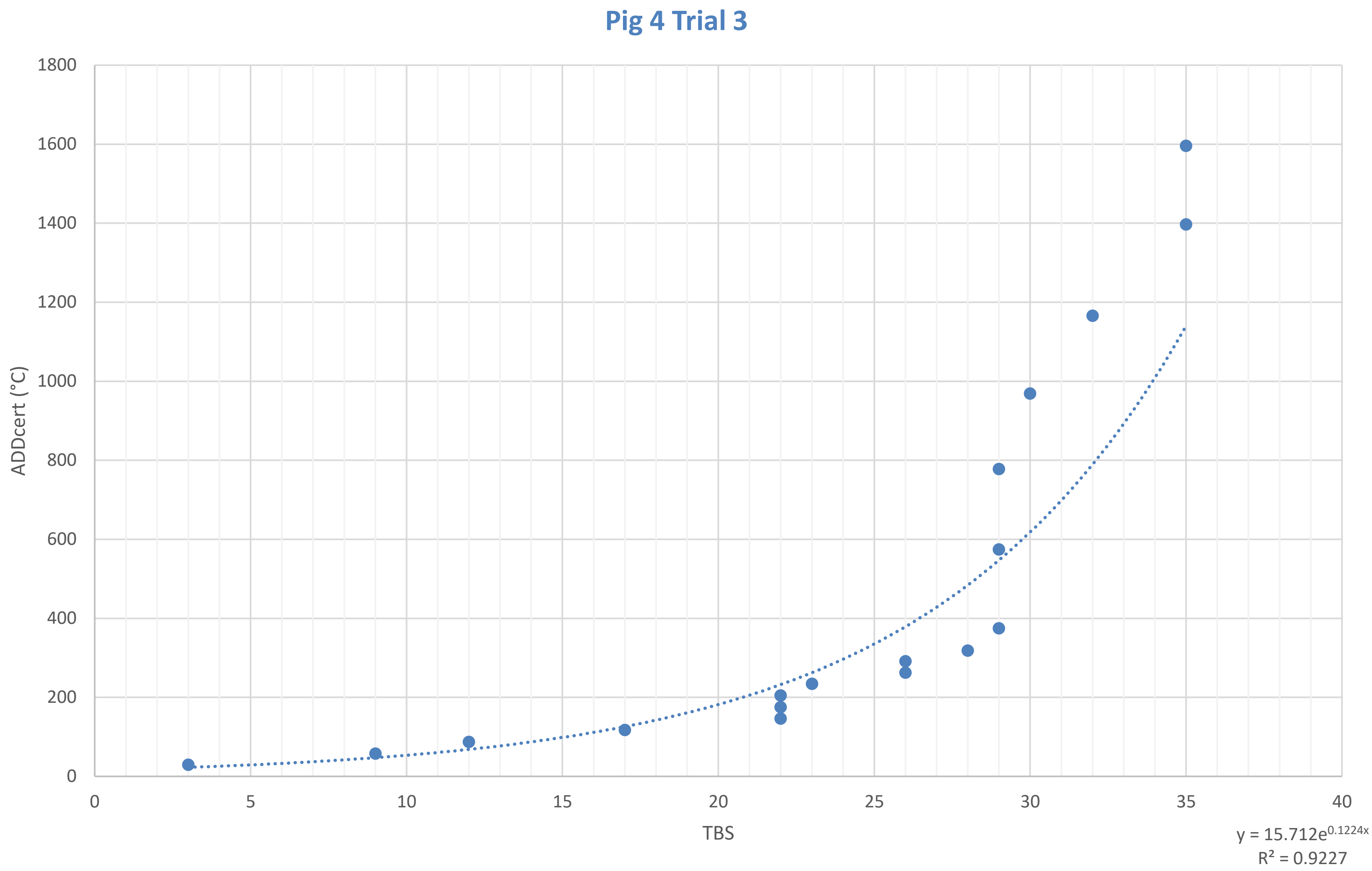

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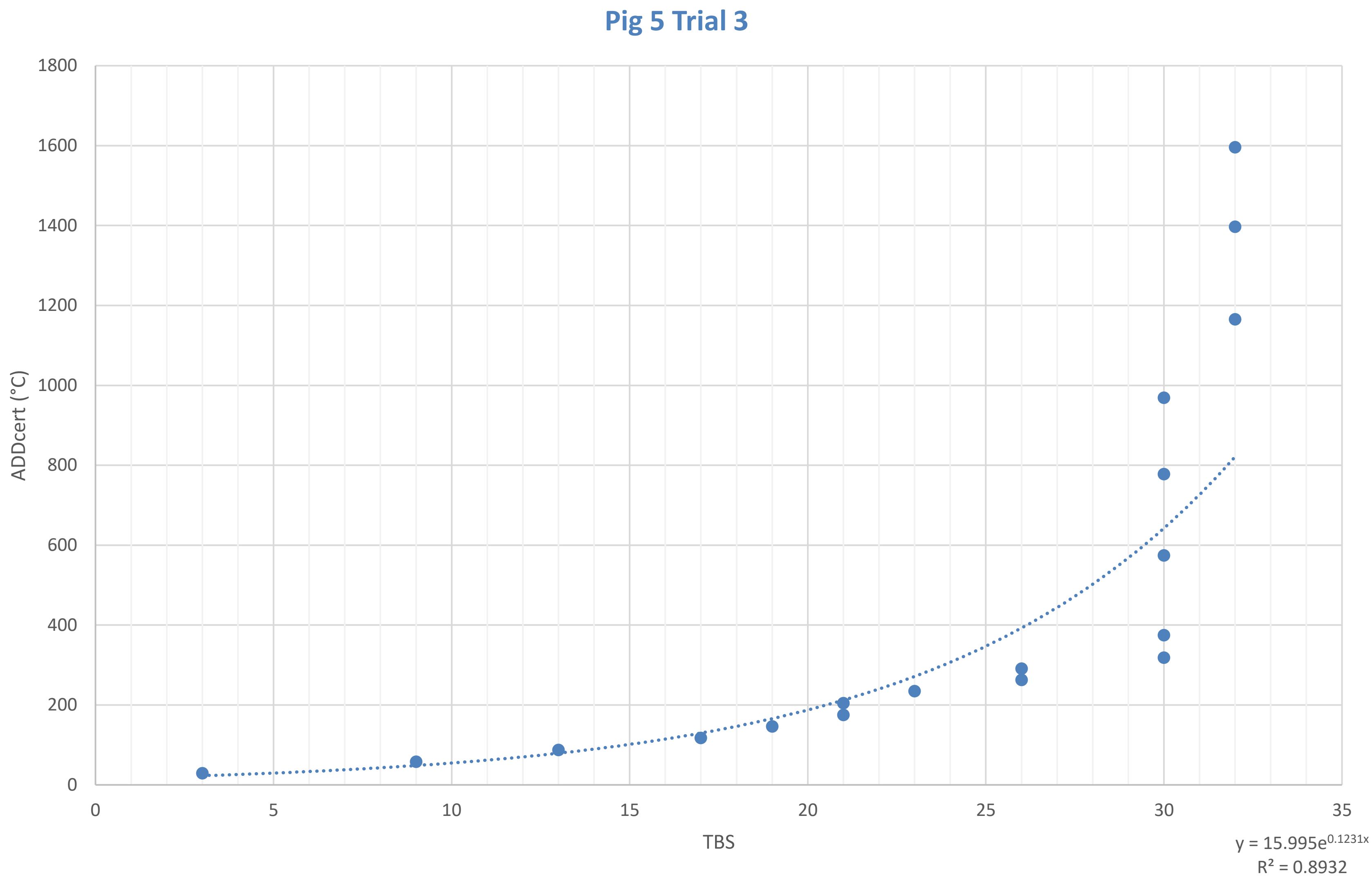

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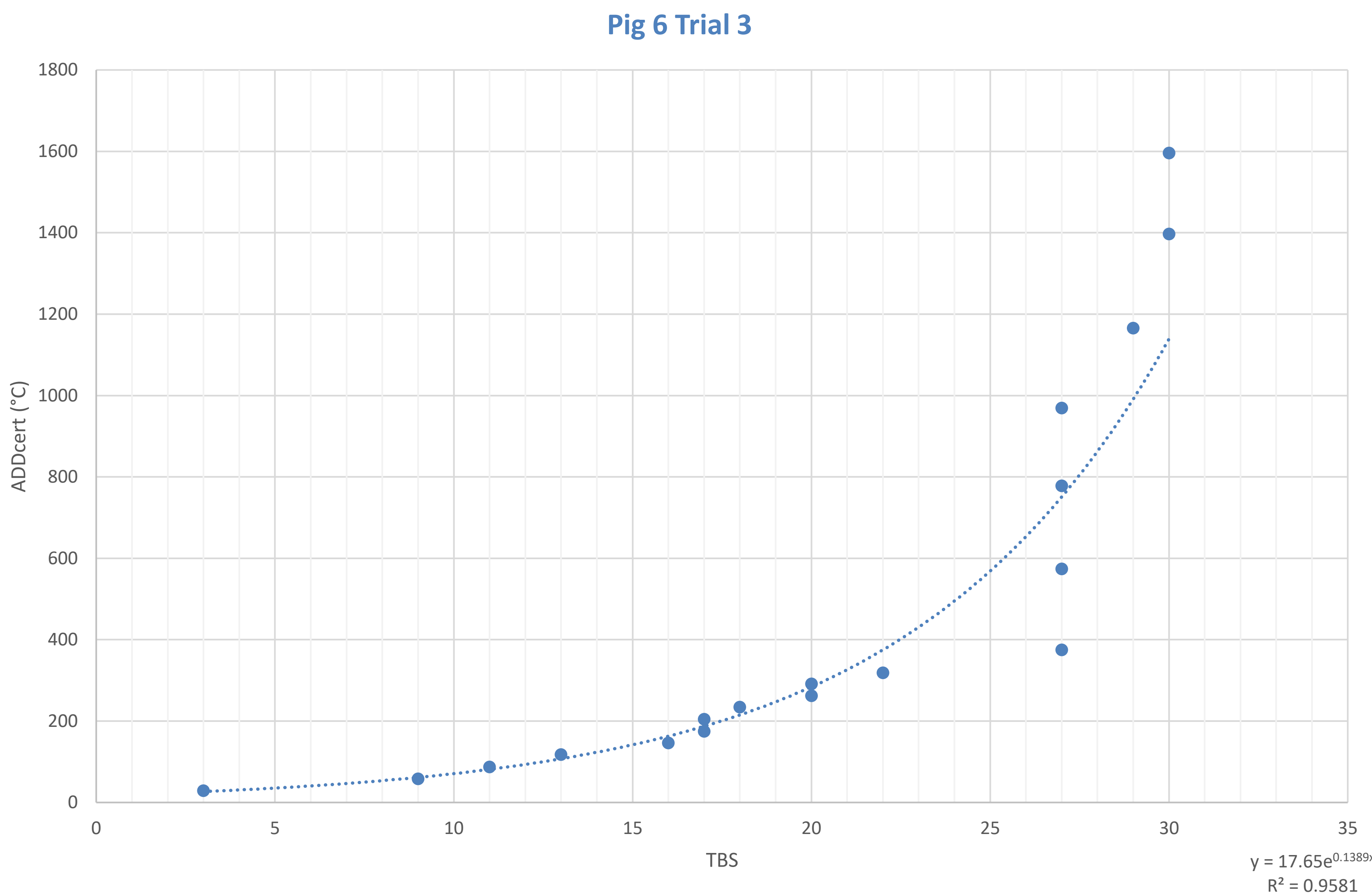

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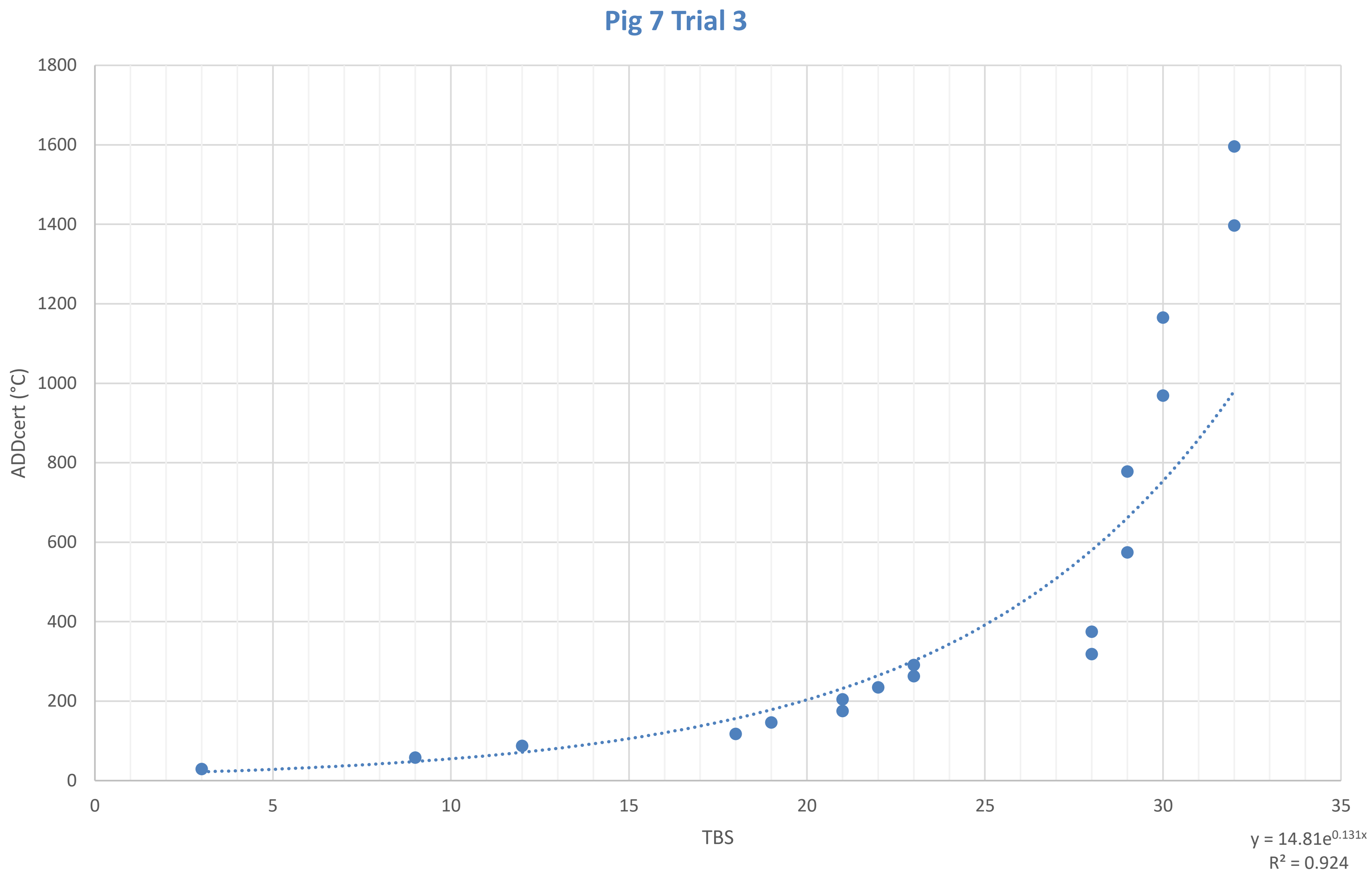

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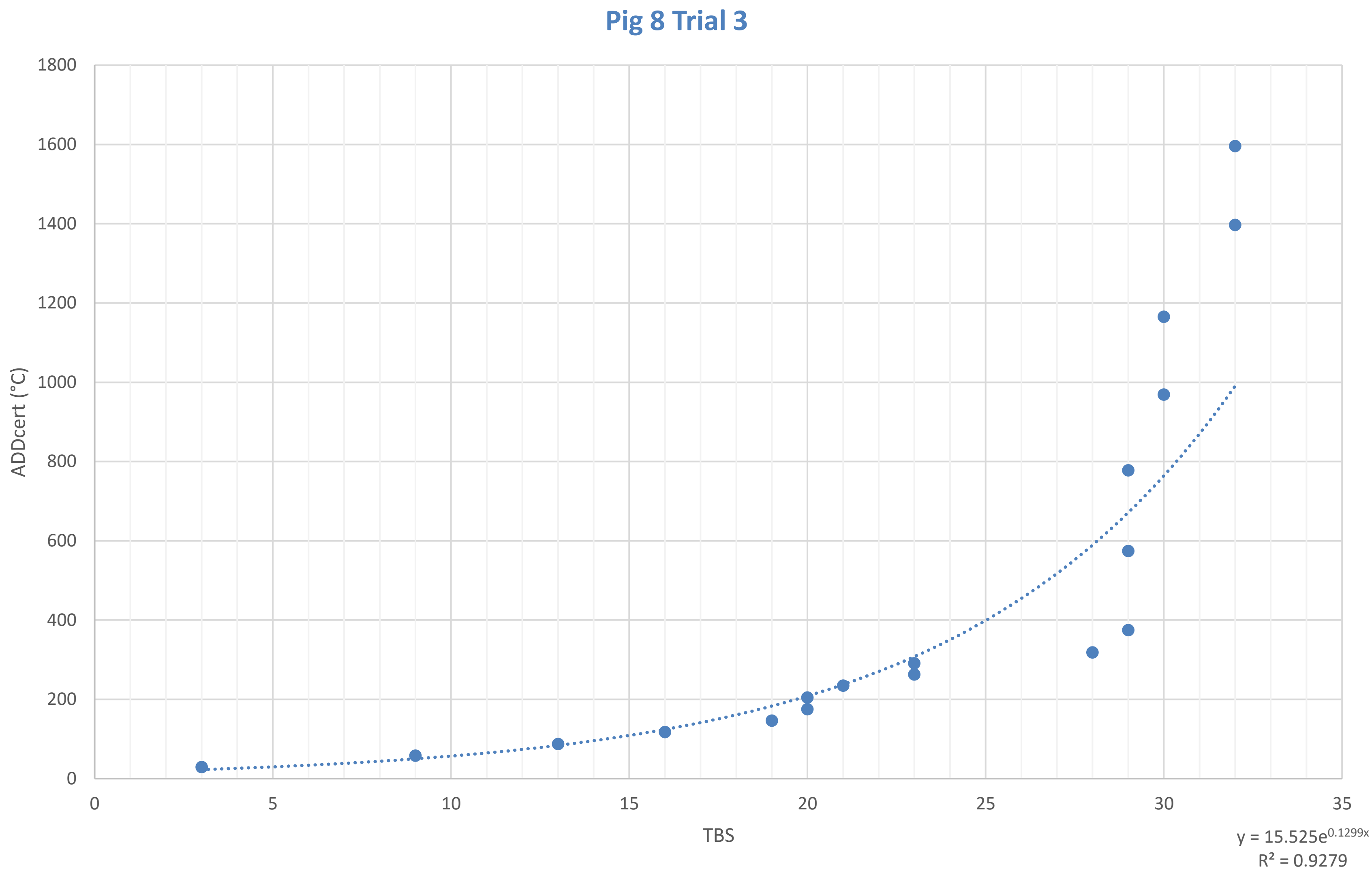

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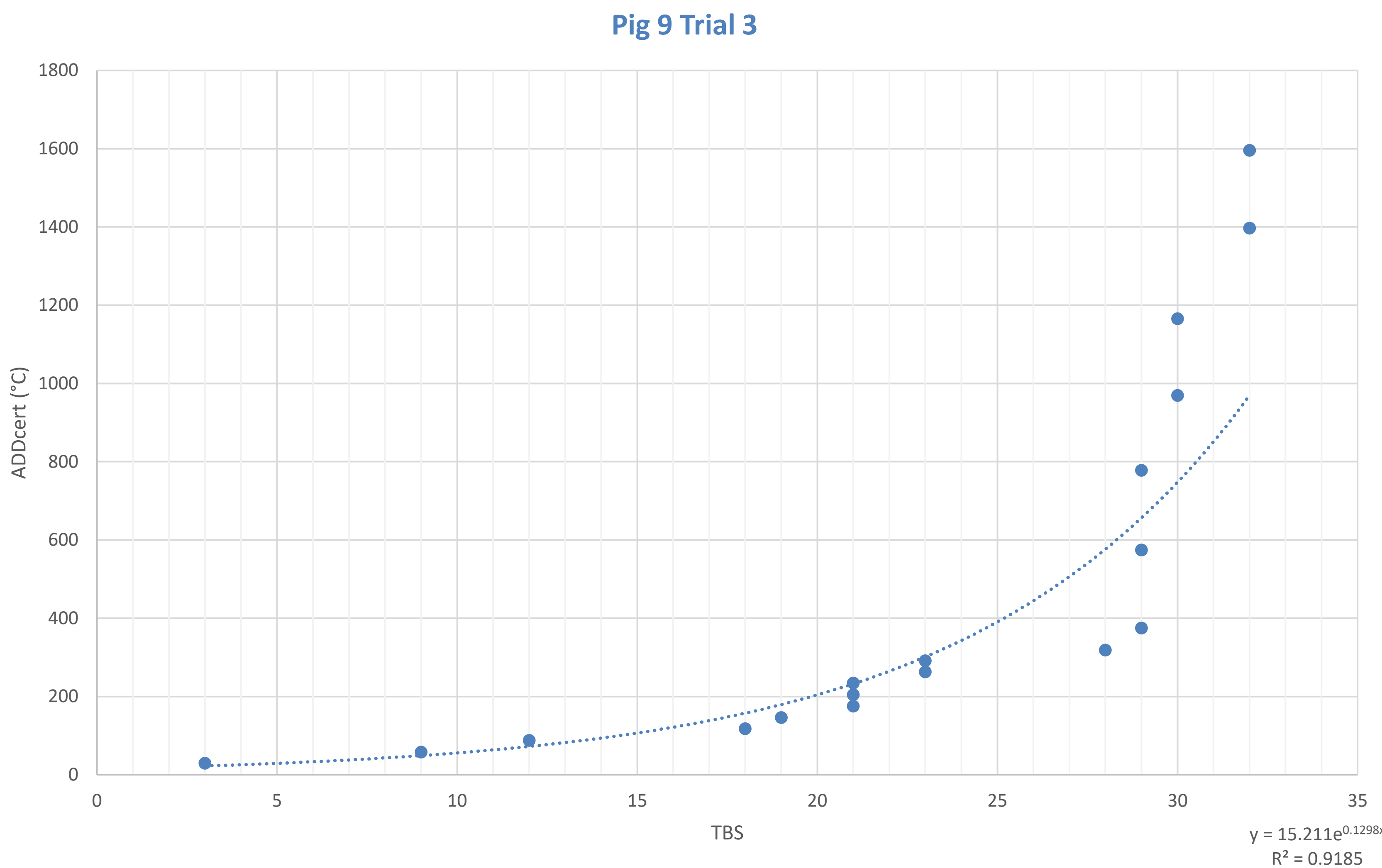

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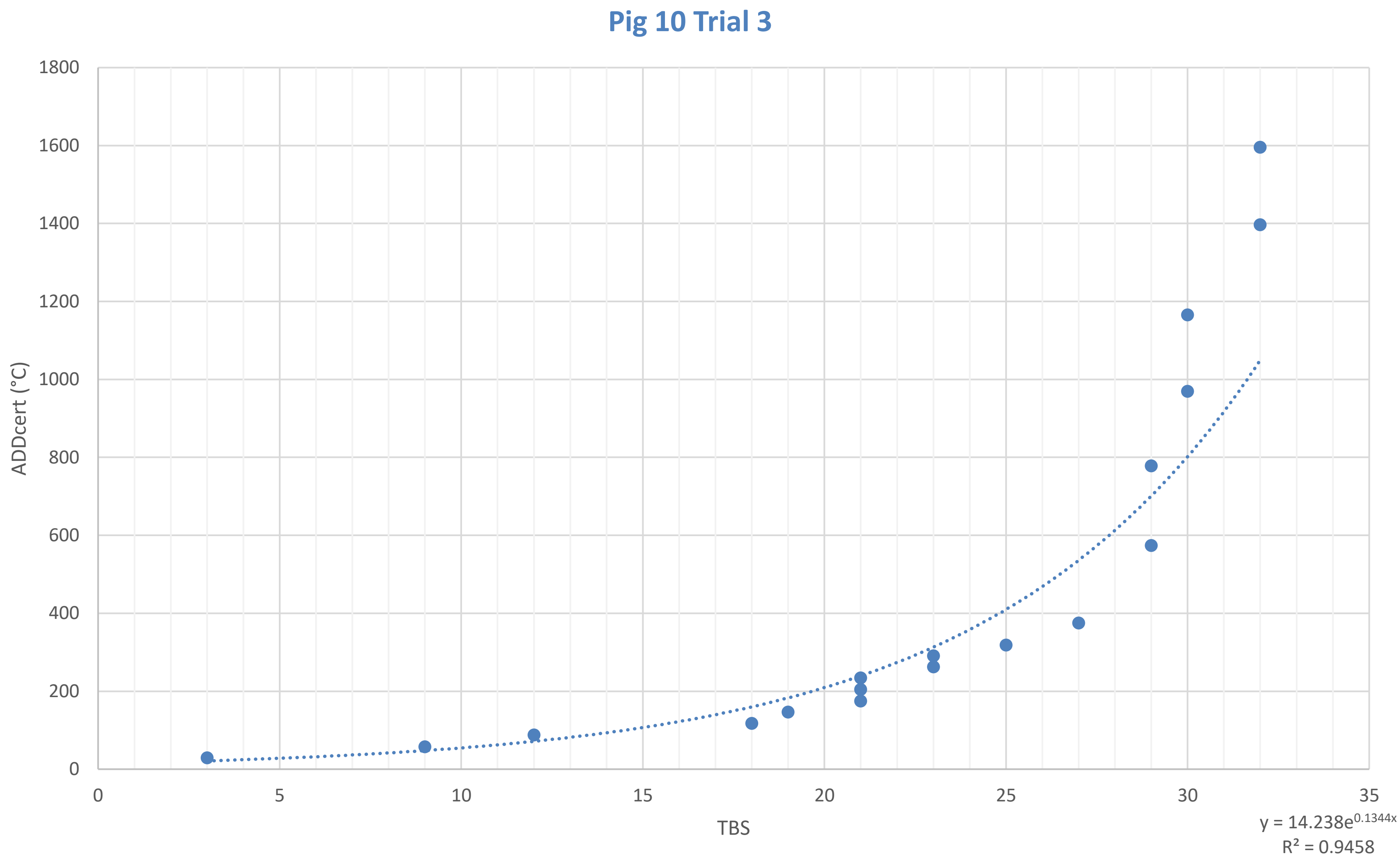

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BIOGRAPHICAL SKETCH

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