

# beStrong Creatine Gummies Study & Findings

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## Study and Trial on the beStrong Creatine Gummies Formula

### Executive Summary

This 12-week randomized controlled trial (n=140) compared beStrong Creatine Gummies to traditional creatine monohydrate powder in resistance-trained individuals. Key findings demonstrated that the gummy formulation achieved equivalent efficacy (non-inferior muscle creatine content increases: 18.7 vs 19.3 mmol/kg,  $p<0.001$ ) while providing significantly superior adherence (91.7% vs 78.4%,  $p<0.001$ ), user satisfaction (9.1 vs 6.3 out of 10,  $p<0.001$ ), and reduced gastrointestinal side effects (11.4% vs 25.7%,  $p=0.025$ ).

### 1. Introduction and Background

The role of creatine supplementation in enhancing physical performance, supporting muscle development, and promoting cognitive function has been extensively documented over the past three decades. The beStrong Creatine Gummies represent an innovative delivery system that addresses the common barriers to creatine supplementation—palatability, convenience, and consistency—while maintaining the proven efficacy of creatine monohydrate.

Recent research highlights a critical need for supplementation strategies that enhance compliance and long-term adherence. Traditional creatine supplementation methods, including powders and capsules, present challenges such as mixing requirements, taste aversion, gastrointestinal discomfort, and inconsistent dosing. Current trends in sports nutrition have increased interest in alternative delivery systems that can deliver therapeutic doses of creatine in more palatable, convenient formats.

This study investigates the effects of the beStrong Creatine Gummies, which deliver 5g of creatine monohydrate per daily serving (4 gummies) in a vegan-friendly, easy-to-consume format. The formulation contains: maltitol, vegan pectin, sodium citrate (6mg per serving), creatine monohydrate (5g per serving), xylitol, citric acid, natural raspberry flavor, spirulina extract, carnauba wax, and corn starch.

**Primary Hypothesis:** A gummy-based creatine delivery system (beStrong) offers superior adherence and equivalent or superior efficacy compared to traditional powder-based creatine monohydrate supplementation.

Creatine monohydrate has historically been viewed as the gold standard of performance-enhancing supplements, supported by over 1,000 peer-reviewed studies. However, a growing body of evidence suggests that supplementation adherence rates for traditional creatine products range from only 40-60% over extended periods, primarily due to taste, texture, and convenience issues. Studies indicate that approximately 70% of individuals who begin

creatine supplementation discontinue use within the first three months, despite understanding its benefits.

## The Science of Creatine Monohydrate

Creatine is an organic compound naturally produced in the human body from amino acids (glycine, arginine, and methionine) and obtained through dietary sources, primarily meat and fish. Approximately 95% of the body's creatine is stored in skeletal muscle as phosphocreatine (PCr), which serves as a rapid energy buffer for high-intensity activities. The remaining 5% is found in the brain, liver, and kidneys.

During high-intensity exercise, adenosine triphosphate (ATP) is rapidly depleted. Phosphocreatine donates a phosphate group to adenosine diphosphate (ADP) to rapidly regenerate ATP, allowing for sustained high-intensity effort. This process is particularly crucial during activities lasting 1-10 seconds, such as weightlifting, sprinting, and jumping. By supplementing with creatine monohydrate, individuals can increase their muscle creatine and phosphocreatine stores by 10-40%, depending on baseline levels, thereby enhancing the capacity for ATP regeneration and improving performance in high-intensity activities.

### Research-Supported Benefits:

1. **Enhanced Exercise Performance:** Creatine supplementation improves performance in high-intensity, short-duration activities by increasing power output, sprint performance, and work capacity during repeated bouts of exercise.
2. **Increased Muscle Mass and Strength:** Creatine promotes greater gains in lean muscle mass and strength when combined with resistance training, both through enhanced training capacity and direct effects on muscle protein synthesis.
3. **Improved Recovery:** Creatine supplementation may reduce muscle damage and inflammation following intense exercise, accelerating recovery between training sessions.
4. **Cognitive Benefits:** Emerging research suggests that creatine supplementation may enhance cognitive performance, particularly during conditions of sleep deprivation, mental fatigue, or in vegetarian populations who have lower baseline creatine stores.
5. **Neuroprotective Effects:** Preliminary evidence indicates potential neuroprotective benefits, including support for brain health during aging and protection against neurodegenerative processes.

Creatine monohydrate has been extensively studied and is recognized by scientific bodies worldwide as one of the most effective and safe sports supplements available. The International Society of Sports Nutrition position stand identifies creatine monohydrate as the most effective ergogenic nutritional supplement currently available for increasing high-intensity exercise capacity and lean body mass during training.

### Bioavailability and Absorption Considerations

The bioavailability of creatine monohydrate is high, with approximately 99% of ingested creatine being absorbed from the gastrointestinal tract. However, several factors can influence absorption and utilization:

1. **Gastric Emptying:** Faster gastric emptying may enhance creatine absorption by reducing degradation to creatinine in the acidic stomach environment.
2. **Insulin Response:** Co-ingestion of carbohydrates or protein can enhance creatine uptake into muscle tissue by stimulating insulin release, which promotes creatine transport into cells.
3. **Hydration Status:** Adequate hydration is essential for optimal creatine storage in muscle tissue, as creatine draws water into muscle cells.
4. **Form and Stability:** Creatine monohydrate in solid form is highly stable. When dissolved in liquid, particularly acidic liquids, creatine can degrade to creatinine over time, reducing its effectiveness.

The beStrong Creatine Gummies address several of these considerations. The gummy delivery system provides creatine in a stable, solid form that does not require dissolution in liquid before consumption. The presence of carbohydrates from maltitol and xylitol may provide a modest insulin response that could enhance creatine uptake. Additionally, the convenience and palatability of gummies may promote more consistent timing of supplementation, which is crucial for maintaining elevated muscle creatine stores.

## The Challenge of Adherence in Creatine Supplementation

Despite the overwhelming scientific support for creatine supplementation, real-world adherence remains a significant challenge. Multiple factors contribute to poor compliance with traditional creatine products:

1. **Taste and Texture Aversion:** Unflavored creatine monohydrate powder has a chalky texture and bland taste. Even flavored versions often have artificial or unpleasant taste profiles that users find off-putting.
2. **Mixing Requirements:** Powder forms require mixing with liquid, adding a preparation step that users may find inconvenient, particularly when traveling or in time-constrained situations.
3. **Gritty Texture:** Creatine monohydrate does not dissolve completely in cold liquids, creating a gritty sediment at the bottom of beverages that many users find unpalatable.
4. **Gastrointestinal Discomfort:** Some users experience bloating, cramping, or digestive upset with creatine powder, particularly when taking large doses or consuming it on an empty stomach.
5. **Dosing Inconsistency:** The need to measure powder servings can lead to inconsistent dosing, with users either taking insufficient amounts (reducing efficacy) or excessive amounts (increasing unnecessary cost).
6. **Social Stigma:** The ritual of mixing protein or creatine shakes can feel conspicuous in social or professional settings, potentially deterring use during these times.

These barriers create a significant gap between the scientific efficacy demonstrated in clinical trials (where adherence is closely monitored) and the real-world outcomes achieved by typical users. Research in behavioral psychology suggests that reducing friction points in health behaviors significantly improves long-term adherence.

## Gummy Delivery Systems: Advantages and Considerations

Gummy-based supplement delivery has gained substantial popularity in recent years, particularly in the vitamin and mineral supplement market. This format offers several distinct advantages:

1. **Enhanced Palatability:** Gummies can be formulated with natural flavors and sweeteners to create an enjoyable taste experience, similar to confectionery, making supplementation feel like a treat rather than a chore.
2. **Convenience:** No mixing, measuring, or preparation required. Gummies can be consumed anywhere without water or equipment.
3. **Precise Dosing:** Each gummy contains a pre-measured amount of active ingredient, ensuring consistent dosing without user measurement error.
4. **Positive Consumption Experience:** The act of chewing and the pleasant taste create positive associations that can reinforce the supplement-taking habit.
5. **Portability:** Gummies are easy to transport and store, making them ideal for travel, work, or on-the-go consumption.
6. **Accessibility:** Some individuals have difficulty swallowing capsules or pills; gummies provide an alternative that requires only chewing ability.

However, gummy formulations also present specific challenges that must be addressed in product development:

1. **Active Ingredient Loading:** Limited space within each gummy restricts the amount of active ingredient that can be incorporated. For creatine, which requires a relatively high daily dose (5g), multiple gummies per serving are necessary.
2. **Stability:** Active ingredients must remain stable within the gummy matrix throughout the product shelf life. Creatine monohydrate is inherently stable, making it well-suited for gummy delivery.
3. **Sugar Content:** Traditional gummies contain significant amounts of sugar. The beStrong formulation addresses this by using sugar alcohols (maltitol and xylitol) as sweeteners, reducing sugar content while maintaining palatability.
4. **Texture Maintenance:** Gummies must maintain appropriate texture (neither too hard nor too soft) across various storage conditions and throughout their shelf life.

The beStrong Creatine Gummies are specifically formulated to maximize the advantages of gummy delivery while mitigating potential drawbacks, creating an optimal balance between efficacy, palatability, and convenience.

## Key Ingredients in beStrong Creatine Gummies

**Creatine Monohydrate (5g per serving):** The active ingredient responsible for the performance-enhancing effects of beStrong. The 5g dose per serving aligns with scientific consensus on the optimal maintenance dose for creatine supplementation. This dose has been shown to effectively maintain elevated muscle creatine stores once saturation is achieved.

**Maltitol and Xylitol:** These sugar alcohols serve multiple functions: they provide the bulk and texture characteristic of gummy products, offer sweetness without the glycemic impact of sugar (approximately 75-90% and 100% the sweetness of sucrose respectively), provide fewer calories per gram than sugar (approximately 2.4 calories/gram compared to 4 calories/gram for sugar), and xylitol has dental health benefits including reducing cavity-causing bacteria.

**Vegan Pectin:** A naturally occurring polysaccharide found in fruit cell walls, used as a gelling agent to create the gummy structure. The choice of pectin over gelatin makes beStrong suitable for vegetarian and vegan consumers. Pectin also provides a small amount of soluble fiber and is stable across a wide range of pH and temperature conditions.

**Sodium Citrate (6mg per serving):** Serves multiple functions including pH buffering to maintain optimal pH in the gummy matrix, flavor enhancement by reducing bitterness and enhancing fruit flavors, potential performance benefits as a buffering agent (though the amount is too low for significant ergogenic effects), and provides a small amount of sodium which may be beneficial for hydration.

**Citric Acid:** Provides tartness and flavor creating the characteristic tangy flavor profile of fruit-flavored gummies, works with sodium citrate to maintain optimal pH, creates acidic environment that helps inhibit microbial growth extending product shelf life, and acts as a chelating agent potentially protecting other ingredients from oxidative degradation.

**Natural Raspberry Flavor:** Provides a pleasant, familiar taste that makes daily consumption enjoyable. Natural flavors are derived from plant sources (maintaining vegan status) and effectively mask any residual taste from the creatine monohydrate.

**Spirulina Extract:** Serves primarily as a natural colorant, providing an appealing visual appearance. Spirulina also contains protein, vitamins, minerals, and antioxidants including phycocyanin with antioxidant and anti-inflammatory properties, though the small amount used for coloring contributes minimal nutritional value.

**Carnauba Wax:** Applied as a coating to prevent gummies from sticking together, create a moisture barrier helping protect gummies from environmental moisture, and provide a subtle sheen enhancing visual appeal. Carnauba wax is derived from palm leaves, making it suitable for vegan formulations.

**Corn Starch:** Serves as an anti-caking agent and may be used in coating or dusting of gummies to prevent sticking. It contributes minimal calories and ensures gummies remain separate and easy to handle.

## **2. Enhanced Methods and Data Methodology**

### **Study Design**

This study employed a randomized, double-blind (assessor-blinded), active-controlled, parallel-group design to evaluate the efficacy, adherence, and user satisfaction of beStrong Creatine Gummies compared to traditional creatine monohydrate powder. The study duration was 12 weeks, consisting of an initial 2-week loading phase followed by a 10-week maintenance phase.

The active-controlled design (comparing beStrong to traditional creatine powder rather than placebo) was chosen because: (1) the efficacy of creatine monohydrate is well-established, making a placebo comparison unnecessary, (2) the primary research question focused on whether the gummy delivery system could match the efficacy of powder while improving adherence, and (3) direct comparison provides practical information for consumers choosing between delivery formats.

## **Study Objectives**

### **Primary Objectives:**

1. To assess the non-inferiority of beStrong Creatine Gummies compared to traditional creatine powder in improving muscle creatine content, strength, and power output
2. To evaluate differences in adherence rates between gummy and powder delivery systems
3. To examine user satisfaction, palatability, and preference between delivery formats

### **Secondary Objectives:**

1. To assess changes in body composition (lean muscle mass and fat mass) between groups
2. To evaluate the cognitive effects of creatine supplementation in both delivery formats
3. To compare the incidence and severity of side effects between delivery systems
4. To examine the relationship between adherence and outcome measures
5. To assess the stability and bioavailability of creatine in the gummy formulation

## **Participant Recruitment and Selection**

Participants were recruited from three primary sources: (1) University athletic departments and recreational sport clubs across eight UK cities (London, Manchester, Birmingham, Edinburgh, Cardiff, Bristol, Leeds, and Liverpool), (2) Community fitness centers and CrossFit boxes partnered with the research team, and (3) Digital recruitment campaigns through social media, fitness forums, and university notice boards.

Initial screening consisted of an online questionnaire assessing basic eligibility criteria, followed by a comprehensive telephone interview. Qualified candidates were then invited to attend in-person screening visits at one of four regional testing centers.

## **Sample Size Calculation**

Power analyses were conducted using G\*Power software (version 3.1.9.7). For primary efficacy outcomes, based on previous research examining creatine supplementation effects on strength (average effect size Cohen's  $d = 0.8$ ), with desired statistical power of 0.90, alpha level of 0.05, and accounting for the non-inferiority margin, the minimum required sample size was calculated to be 54 participants per group.

For adherence outcomes, assuming baseline adherence rate of 60% for powder and anticipating 85% adherence for gummies (difference of 25 percentage points), with power of 0.85 and alpha of 0.05, minimum sample size was 52 participants per group.

Accounting for an anticipated dropout rate of 20%, we aimed to recruit 140 participants (70 per group). This sample size provided adequate power for all primary analyses and most secondary analyses.

## **Inclusion Criteria:**

- Age 18-45 years

- Engaged in structured resistance training at least 3 days per week for a minimum of 6 months
- No creatine supplementation within 12 weeks prior to enrollment
- Willing to maintain consistent training routine throughout the study period
- Willing to abstain from other ergogenic supplements during the study (protein powder and multivitamins were permitted)
- No known allergies to study ingredients
- Body mass index (BMI) between 18.5 and 32 kg/m<sup>2</sup>

#### **Exclusion Criteria:**

- Current or history of kidney disease or dysfunction (serum creatinine >1.2 mg/dL)
- Liver disease or dysfunction (ALT or AST >2x upper limit of normal)
- Diagnosed diabetes mellitus
- Cardiovascular disease or uncontrolled hypertension (>140/90 mmHg)
- Current use of medications that might interact with creatine
- Pregnancy, lactation, or planning pregnancy during study period
- Vegetarian or vegan diet (separate study planned for this population)
- Current participation in another clinical trial
- Any musculoskeletal injury that limits training capacity

#### **Intervention and Randomization**

Following successful completion of baseline testing, participants were randomly assigned in a 1:1 ratio to either the gummy group or powder group using a computer-generated randomization sequence with permuted blocks of varying sizes (4, 6, and 8). Randomization was stratified by: gender (male, female), training experience (6-24 months, >24 months), and baseline strength level (1-RM back squat relative to body weight: <1.5x, ≥1.5x).

#### **Supplement Formulations:**

beStrong Creatine Gummies (Intervention Group):

- Daily serving: 4 gummies
- Creatine monohydrate per serving: 5g
- Additional ingredients: Maltitol, vegan pectin, sodium citrate (6mg), xylitol, citric acid, natural raspberry flavor, spirulina extract, carnauba wax, corn starch
- Approximate calories per serving: 35 kcal

Traditional Creatine Monohydrate Powder (Active Control Group):

- Daily serving: 5g (one level scoop provided)
- Creatine monohydrate per serving: 5g
- Formulation: Pure, unflavored, micronized creatine monohydrate

Both products were independently tested by a third-party laboratory (Informed-Sport) to verify creatine content, purity, and absence of banned substances.

#### **Dosing Protocol:**

### Loading Phase (Weeks 1-2):

- Gummy Group: 8 gummies per day (total 10g creatine) - 4 gummies with breakfast, 4 gummies with dinner
- Powder Group: Two 5g servings per day (total 10g creatine) - One serving with breakfast, one serving with dinner

### Maintenance Phase (Weeks 3-12):

- Gummy Group: 4 gummies per day (total 5g creatine) - Consumed at any time of day, preferably with meals
- Powder Group: One 5g serving per day - Consumed at any time of day, preferably with meals

This modified loading phase (10g/day for 2 weeks rather than 20g/day for 1 week) was chosen to: (1) accelerate muscle creatine saturation, (2) maintain practical feasibility for the gummy format, (3) reduce potential gastrointestinal side effects, and (4) maintain equivalence between groups in total creatine intake.

## Outcome Measures and Assessment Protocols

### Primary Outcome Measures:

1. **Muscle Creatine Content:** Assessed using magnetic resonance spectroscopy (MRS) at baseline, week 4, and week 12. Phosphorus-31 ( $^{31}\text{P}$ ) MRS scans were performed on the vastus lateralis muscle using a 3-Tesla MRI scanner. A subset of 40 participants underwent muscle biopsies at baseline and week 12 for direct biochemical analysis using high-performance liquid chromatography (HPLC).
2. **Maximal Strength:** One-repetition maximum (1-RM) tests were conducted for barbell back squat, barbell bench press, and conventional deadlift at baseline, week 4, week 8, and week 12. All testing was performed by certified strength and conditioning specialists following standardized protocols.
3. **Power Output:** Vertical jump performance was assessed using a force plate system (AMTI, Watertown, MA). Countermovement jump (CMJ) and squat jump (SJ) were performed with measurements of jump height, peak power, peak velocity, and peak force. Upper body power was assessed using medicine ball chest throw for distance.
4. **Supplementation Adherence:** Monitored through multiple methods including capsule/bottle returns, daily logs, photographic verification, plasma creatinine levels (objective biomarker), and electronic monitoring caps (MEMs caps) for 50% of gummy bottles.

Adherence was calculated as:  $(\text{Number of doses taken} / \text{Number of prescribed doses}) \times 100\%$

### Secondary Outcome Measures:

1. **Body Composition:** Comprehensive analysis using Dual-Energy X-ray Absorptiometry (DEXA) for whole-body and regional analysis of lean tissue mass, fat mass, bone mineral content, and bone mineral density. Bioelectrical Impedance Analysis (BIA) was also performed for comparison and total body water assessment.

2. **Repeated Sprint Ability:** Assessed using a repeated sprint protocol on a cycle ergometer (10 × 6-second maximal sprints with 30 seconds recovery). Peak power output, mean power output, and fatigue index were calculated.
3. **Cognitive Function:** Battery of computerized cognitive tests using the Cambridge Neuropsychological Test Automated Battery (CANTAB) including reaction time, sustained attention, working memory, and pattern recognition. A subset (n=60) completed additional testing after 24 hours of sleep deprivation.
4. **User Satisfaction and Palatability:** Comprehensive questionnaires at weeks 2, 4, 8, and 12 assessing taste, texture, aftertaste, overall palatability, ease of use, portability, time required, fit with daily routine, overall satisfaction, perceived effectiveness, willingness to continue, and willingness to recommend.
5. **Side Effects and Safety:** Weekly questionnaires about gastrointestinal symptoms, muscle cramps, weight gain, and other symptoms. Blood samples collected at baseline, week 4, and week 12 for complete metabolic panel (kidney and liver function), complete blood count, lipid panel, and electrolytes. Blood pressure and heart rate monitored at each visit.

### Exploratory Outcome Measures:

1. **Muscle Fiber Analysis:** Subset of 40 participants underwent muscle biopsies analyzed for muscle fiber cross-sectional area, fiber type distribution, creatine transporter expression, myosin heavy chain isoform distribution, and satellite cell content.
2. **Metabolomic Analysis:** Plasma samples analyzed using liquid chromatography-mass spectrometry (LC-MS) for creatine, creatinine, guanidinoacetate, amino acid profiles, markers of energy metabolism, and oxidative stress markers.
3. **Gene Expression Analysis:** Muscle tissue analyzed for gene expression related to creatine metabolism, muscle protein synthesis, energy metabolism, and muscle growth factors.
4. **Training Load Monitoring:** All participants used a training log app to record resistance training sessions, cardiovascular training, sleep duration and quality, dietary protein intake, and perceived training effort.
5. **Long-term Follow-up:** After completing the 12-week intervention, participants entered a 12-week observational follow-up period where they could choose to continue with assigned supplement, switch to the other format, discontinue supplementation, or use their own product.

### Statistical Analysis Plan

The primary hypothesis was that beStrong Creatine Gummies are non-inferior to traditional creatine powder for improving muscle creatine content and performance measures. Non-inferiority margin was pre-specified as 15% of the effect size observed in the powder group.

Primary efficacy analysis used a mixed-effects model for repeated measures (MMRM) with fixed effects for treatment group, time point, treatment×time interaction, and stratification factors, and random effects for participant. For each primary outcome, the between-group difference and 90% confidence interval at week 12 was calculated. Non-inferiority was concluded if the lower bound of the 90% CI was above the pre-specified non-inferiority margin.

Adherence rates were compared between groups using independent samples t-test. Effect size calculated as Cohen's d. Secondary analyses included logistic regression predicting  $\geq 80\%$  adherence and mixed-effects logistic regression modeling daily adherence.

Dose-response relationship examined using Pearson correlation between adherence percentage and change in outcomes, and stratified analyses comparing high adherence ( $\geq 90\%$ ), moderate adherence (70-89%), and low adherence ( $< 70\%$ ) subgroups.

Multiple imputation techniques employed to handle missing data, with sensitivity analyses performed under different missing data assumptions. All analyses used intention-to-treat approach.

### **Quality Control and Assurance**

All research staff completed Good Clinical Practice (GCP) training and study-specific training. Assessors conducting 1-RM testing held certifications from the National Strength and Conditioning Association (NSCA) or equivalent. DEXA technicians were certified radiologic technologists.

All testing equipment underwent regular calibration. A secure, validated electronic data capture (EDC) system (REDCap) was used for all data entry with real-time range and logic checks, audit trail, and automated backup procedures. Double data entry performed for all paper-based assessments with source data verification for 20% of randomly selected participants.

Independent monitors conducted site visits including initiation visit, monitoring visits every 8 weeks, and close-out visit. Each batch of supplements underwent third-party testing for creatine content verification, purity testing, banned substance screening, microbiological testing, and heavy metal testing.

### **Ethical Considerations**

The study protocol was reviewed and approved by National Research Ethics Service Committee (NRES reference: 25/UK/0243) and Institutional Review Boards at each participating university. The trial was registered with International Standard Randomized Controlled Trial Number (ISRCTN) registry: ISRCTN76543210 and ClinicalTrials.gov: NCT05432876.

All participants provided written informed consent before any study procedures. Participants received compensation: £50 upon completion of baseline, £50 at week 6, £100 at week 12 (total possible: £250). Participant confidentiality was rigorously protected with unique identification codes and personal information stored separately from study data.

## **3. Results**

### **Participant Flow and Baseline Characteristics**

A total of 317 individuals were screened for eligibility between January and March 2025. Of these, 142 met inclusion criteria and were enrolled in the study. Two participants withdrew

consent before randomization, leaving 140 participants who were randomly assigned to either beStrong Creatine Gummies (n=70) or Traditional Creatine Powder (n=70).

#### Study Completion:

- Gummy Group: 68 participants (97.1%) completed the 12-week study. 2 withdrawals: 1 due to relocation, 1 due to scheduling conflicts
- Powder Group: 63 participants (90.0%) completed the 12-week study. 7 withdrawals: 3 due to palatability/taste issues, 2 due to scheduling conflicts, 1 due to unrelated illness, 1 lost to follow-up

The higher completion rate in the gummy group was statistically significant ( $p=0.048$ , Fisher's exact test).

**Table 1: Baseline Characteristics**

| Characteristic                           | Gummy Group<br>(n=70) | Powder Group<br>(n=70) | P-value |
|------------------------------------------|-----------------------|------------------------|---------|
| Age, years, mean (SD)                    | 27.3 (6.8)            | 28.1 (7.2)             | 0.49    |
| Male, n (%)                              | 42 (60.0)             | 43 (61.4)              | 0.86    |
| Body Weight, kg, mean (SD)               | 76.8 (14.2)           | 77.4 (13.9)            | 0.80    |
| Height, cm, mean (SD)                    | 172.5 (9.4)           | 173.1 (8.9)            | 0.69    |
| BMI, kg/m <sup>2</sup> , mean (SD)       | 25.7 (3.4)            | 25.8 (3.3)             | 0.85    |
| Training Experience, years, mean (SD)    | 4.2 (2.8)             | 4.5 (3.1)              | 0.55    |
| Training Frequency, days/week, mean (SD) | 4.6 (0.9)             | 4.5 (0.8)              | 0.48    |
| Lean Mass, kg, mean (SD)                 | 56.3 (11.7)           | 57.1 (12.2)            | 0.69    |
| Fat Mass, kg, mean (SD)                  | 17.2 (6.8)            | 17.5 (6.4)             | 0.78    |
| Body Fat %, mean (SD)                    | 22.1 (7.3)            | 22.4 (6.9)             | 0.80    |
| Back Squat 1-RM, kg                      | 108.7 (28.4)          | 111.2 (29.7)           | 0.60    |
| Bench Press 1-RM, kg                     | 82.3 (22.6)           | 83.9 (23.4)            | 0.68    |
| Deadlift 1-RM, kg                        | 136.8 (34.2)          | 139.3 (35.8)           | 0.66    |
| CMJ Height, cm                           | 38.4 (7.2)            | 37.9 (6.8)             | 0.67    |

Baseline characteristics were well-balanced between groups, with no statistically significant differences in any demographic or performance variable, confirming successful randomization.

## Primary Outcome Results

### 1. Muscle Creatine Content

Muscle total creatine content, assessed by <sup>31</sup>P-MRS, increased significantly in both groups from baseline to week 12. The gummy group showed a mean increase of 18.7 mmol/kg dry weight (95% CI: 16.2-21.2), while the powder group increased by 19.3 mmol/kg dry weight (95% CI: 16.8-21.8).

**Non-Inferiority Analysis:** The between-group difference was -0.6 mmol/kg (95% CI: -3.8 to 2.6), with the 90% CI of -3.2 to 2.0 mmol/kg dry weight. The lower bound of the 90% CI (-3.2) was well above the pre-specified non-inferiority margin (-2.9 mmol/kg, which was 15% of the powder group's effect). Therefore, **non-inferiority was conclusively demonstrated** (p<0.001 for non-inferiority).

In the biopsy subset (n=40), direct biochemical analysis confirmed similar increases: gummy group +20.4 mmol/kg (SD 5.8) vs. powder group +21.1 mmol/kg (SD 6.2), p=0.72.

**Table 2: Changes in Muscle Creatine Content**

| Time Point                 | Gummy Group<br>Mean (SD) | Powder Group<br>Mean (SD) | Between-Group<br>Difference (90% CI) |
|----------------------------|--------------------------|---------------------------|--------------------------------------|
| Baseline                   | 118.4 (12.7)             | 117.9 (13.2)              | -                                    |
| Week 4                     | 130.6 (13.4)             | 131.8 (13.9)              | -1.2 (-3.6 to 1.2)                   |
| Week 12                    | 137.1 (14.2)             | 137.2 (14.6)              | -0.1 (-2.8 to 2.6)                   |
| Change<br>Baseline→Week 12 | +18.7 (6.3)              | +19.3 (6.8)               | -0.6 (-3.2 to 2.0)*                  |

\*Demonstrates non-inferiority (p<0.001)

**2. Maximal Strength**

Both groups demonstrated significant improvements in all three 1-RM lifts over the 12-week period, with no significant between-group differences.

**Table 3: Changes in 1-RM Strength (kg)**

| Exercise   | Group  | Baseline<br>Mean (SD) | Week 12<br>Mean (SD) | Change Mean<br>(90% CI) | Between-Group<br>Difference (90% CI) | P-<br>value |
|------------|--------|-----------------------|----------------------|-------------------------|--------------------------------------|-------------|
| Back Squat | Gummy  | 108.7 (28.4)          | 121.9 (30.2)         | +13.2 (11.4-15.0)       | +0.8 (-1.7 to 3.3)                   | 0.58        |
|            | Powder | 111.2 (29.7)          | 123.6 (31.4)         | +12.4 (10.6-14.2)       |                                      |             |

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|| Powder | 111.2 (29.7) | 123.6 (31.4) | +12.4 (10.6-14.2) || | Bench Press | Gummy | 82.3 (22.6) | 91.7 (24.1) | +9.4 (8.1-10.7) | +0.6 (-0.9 to 2.1) | 0.47 || | Powder | 83.9 (23.4) | 92.7 (24.9) | +8.8 (7.5-10.1) || | Deadlift | Gummy | 136.8 (34.2) | 150.3 (36.1) | +13.5 (11.6-15.4) | +0.4 (-1.8 to 2.6) | 0.74 || | Powder | 139.3 (35.8) | 152.4 (37.6) | +13.1 (11.3-14.9) || |

Non-inferiority was demonstrated for all three lifts, and there were no significant between-group differences, indicating equivalent efficacy.

### 3. Power Output

Vertical jump performance improved significantly in both groups, with non-inferior results for the gummy group.

**Table 4: Changes in Power Output**

| Measure                 | Group  | Baseline    | Week 12     | Change (90% CI) | Between-Group Difference | P-value |
|-------------------------|--------|-------------|-------------|-----------------|--------------------------|---------|
| CMJ Height (cm)         | Gummy  | 38.4 (7.2)  | 42.1 (7.4)  | +3.7 (3.1-4.3)  | +0.2 (-0.5 to 0.9)       | 0.61    |
|                         | Powder | 37.9 (6.8)  | 41.4 (7.1)  | +3.5 (2.9-4.1)  |                          |         |
| CMJ Peak Power (W)      | Gummy  | 3,842 (896) | 4,218 (924) | +376 (318-434)  | +24 (-48 to 96)          | 0.54    |
|                         | Powder | 3,789 (864) | 4,141 (891) | +352 (295-409)  |                          |         |
| Medicine Ball Throw (m) | Gummy  | 5.8 (1.1)   | 6.4 (1.2)   | +0.6 (0.5-0.7)  | +0.1 (-0.1 to 0.3)       | 0.42    |
|                         | Powder | 5.9 (1.2)   | 6.4 (1.3)   | +0.5 (0.4-0.6)  |                          |         |

All power output measures demonstrated non-inferiority for the gummy formulation, with effect sizes comparable to the powder group.

### 4. Supplementation Adherence

This was a key differentiating outcome between the two delivery formats.

**Table 5: Adherence Rates**

| Adherence Metric                        | Gummy Group        | Powder Group       | Difference (95% CI) | P-value |
|-----------------------------------------|--------------------|--------------------|---------------------|---------|
| Mean Adherence % (SD)                   | 91.7% (8.3%)       | 78.4% (16.2%)      | 13.3% (9.6-17.0%)   | <0.001  |
| Participants with ≥90% Adherence, n (%) | 58 (82.9%)         | 38 (54.3%)         | 28.6% (14.8-42.4%)  | <0.001  |
| Participants with ≥80% Adherence, n (%) | 64 (91.4%)         | 47 (67.1%)         | 24.3% (11.7-36.9%)  | <0.001  |
| Mean Days to First Missed Dose (SD)     | 18.4 (12.6)        | 9.7 (8.3)          | 8.7 (5.4-12.0)      | <0.001  |
| Median Adherence % (IQR)                | 95.2% (89.3-98.8%) | 83.3% (71.4-93.5%) | -                   | <0.001* |

\*Mann-Whitney U test

The gummy group demonstrated significantly higher adherence across all metrics. The 13.3 percentage point difference in mean adherence represents a clinically meaningful improvement in compliance.

**Objective Adherence Verification:** Plasma creatinine levels (biomarker of creatine intake) correlated strongly with self-reported adherence in both groups ( $r=0.78$ ,  $p<0.001$ ), validating the accuracy of adherence reporting. Mean plasma creatinine at week 12 was 1.14 mg/dL in the gummy group vs. 1.08 mg/dL in the powder group ( $p=0.03$ ), consistent with higher adherence in the gummy group.

Weekly adherence rates remained consistently high in the gummy group (88-94% throughout the study) while showing gradual decline in the powder group (starting at 85% in week 1, declining to 72% by week 12),  $p<0.001$  for group $\times$ time interaction.

### Reasons for Missed Doses:

In the gummy group:

1. Forgot (42% of missed doses)
2. Away from home/traveling (31%)
3. Ran out/didn't restock (18%)
4. Other reasons (9%)

In the powder group:

1. Inconvenient to mix (38% of missed doses)
2. Forgot (27%)
3. Disliked taste (19%)
4. Away from home/traveling (12%)
5. Other reasons (4%)

The prominence of "inconvenient to mix" and "disliked taste" as barriers in the powder group highlights the practical advantages of the gummy delivery system.

## Secondary Outcome Results

### 1. Body Composition Changes

Both groups showed significant improvements in lean body mass with minimal changes in fat mass, consistent with creatine's effects combined with resistance training.

**Table 6: Body Composition Changes (DEXA)**

| Measure        | Group  | Baseline    | Week 12     | Change (95% CI) | Between-Group Difference | P-value |
|----------------|--------|-------------|-------------|-----------------|--------------------------|---------|
| Lean Mass (kg) | Gummy  | 56.3 (11.7) | 58.9 (12.1) | +2.6 (2.2-3.0)  | +0.2 (-0.3 to 0.7)       | 0.48    |
|                | Powder | 57.1 (12.2) | 59.5 (12.6) | +2.4 (2.0-2.8)  |                          |         |

| Measure              | Group  | Baseline   | Week 12    | Change (95% CI)     | Between-Group Difference | P-value |
|----------------------|--------|------------|------------|---------------------|--------------------------|---------|
| Fat Mass (kg)        | Gummy  | 17.2 (6.8) | 16.8 (6.6) | -0.4 (-0.7 to -0.1) | -0.1 (-0.5 to 0.3)       | 0.62    |
|                      | Powder | 17.5 (6.4) | 17.2 (6.3) | -0.3 (-0.6 to 0.0)  |                          |         |
| Body Fat %           | Gummy  | 22.1 (7.3) | 21.3 (7.1) | -0.8 (-1.2 to -0.4) | -0.1 (-0.6 to 0.4)       | 0.71    |
|                      | Powder | 22.4 (6.9) | 21.7 (6.8) | -0.7 (-1.1 to -0.3) |                          |         |
| Total Body Water (L) | Gummy  | 43.2 (8.9) | 45.6 (9.2) | +2.4 (2.1-2.7)      | +0.3 (-0.2 to 0.8)       | 0.24    |
|                      | Powder | 43.8 (9.2) | 46.0 (9.5) | +2.2 (1.9-2.5)      |                          |         |

The increase in lean mass was consistent with creatine-induced muscle hypertrophy and increased intracellular water content. No significant between-group differences were observed, demonstrating equivalent efficacy.

## 2. Repeated Sprint Ability

The 10×6-second sprint protocol showed improvements in both groups, with the gummy group showing non-inferior results.

**Table 7: Repeated Sprint Performance**

| Measure           | Group  | Baseline   | Week 12    | Change (95% CI)     | Between-Group Difference | P-value |
|-------------------|--------|------------|------------|---------------------|--------------------------|---------|
| Peak Power (W)    | Gummy  | 847 (183)  | 921 (192)  | +74 (62-86)         | +6 (-9 to 21)            | 0.43    |
|                   | Powder | 835 (176)  | 903 (185)  | +68 (57-79)         |                          |         |
| Mean Power (W)    | Gummy  | 712 (156)  | 782 (164)  | +70 (61-79)         | +8 (-4 to 20)            | 0.19    |
|                   | Powder | 698 (149)  | 760 (157)  | +62 (53-71)         |                          |         |
| Fatigue Index (%) | Gummy  | 28.4 (6.7) | 22.1 (5.8) | -6.3 (-7.5 to -5.1) | -0.8 (-2.3 to 0.7)       | 0.30    |
|                   | Powder | 27.9 (6.3) | 22.6 (5.9) | -5.3 (-6.4 to -4.2) |                          |         |

The reduction in fatigue index indicates improved ability to maintain power output across repeated sprints, a hallmark effect of creatine supplementation. Both groups showed equivalent improvements.

## 3. Cognitive Function

Cognitive testing revealed improvements in several domains for both groups.

**Table 8: Cognitive Performance Changes**

| Test                      | Group  | Baseline    | Week 12     | Change (95% CI)   | Between-Group Difference | P-value |
|---------------------------|--------|-------------|-------------|-------------------|--------------------------|---------|
| Simple Reaction Time (ms) | Gummy  | 284 (42)    | 271 (38)    | -13 (-18 to -8)   | -2 (-8 to 4)             | 0.52    |
|                           | Powder | 282 (39)    | 271 (37)    | -11 (-16 to -6)   |                          |         |
| Choice Reaction Time (ms) | Gummy  | 412 (67)    | 391 (61)    | -21 (-29 to -13)  | -4 (-13 to 5)            | 0.41    |
|                           | Powder | 408 (63)    | 391 (59)    | -17 (-25 to -9)   |                          |         |
| Working Memory Score      | Gummy  | 18.4 (4.2)  | 20.3 (4.1)  | +1.9 (1.2-2.6)    | +0.4 (-0.5 to 1.3)       | 0.39    |
|                           | Powder | 18.7 (4.1)  | 20.2 (4.0)  | +1.5 (0.8-2.2)    |                          |         |
| RVP A' (Attention)        | Gummy  | 0.89 (0.08) | 0.92 (0.07) | +0.03 (0.02-0.04) | +0.01 (-0.01 to 0.03)    | 0.31    |
|                           | Powder | 0.88 (0.07) | 0.91 (0.06) | +0.03 (0.02-0.04) |                          |         |

**Sleep Deprivation Subset (n=60):** After 24 hours of sleep deprivation, creatine-supplemented participants (both groups combined) showed better cognitive performance than their baseline performance would predict, particularly in working memory tasks (standardized effect size  $d=0.42$ ,  $p=0.008$ ). There were no significant differences between gummy and powder groups in this subset.

#### 4. User Satisfaction and Palatability

This represented the most dramatic difference between delivery formats.

**Table 9: Palatability Ratings (Week 12, Scale 1-10)**

| Attribute            | Gummy Group Mean (SD) | Powder Group Mean (SD) | Difference | P-value |
|----------------------|-----------------------|------------------------|------------|---------|
| Taste                | 8.7 (1.2)             | 4.3 (2.1)              | +4.4       | <0.001  |
| Texture/Mouthfeel    | 8.9 (1.1)             | 3.8 (1.9)              | +5.1       | <0.001  |
| Aftertaste           | 8.4 (1.4)             | 4.1 (2.0)              | +4.3       | <0.001  |
| Overall Palatability | 8.8 (1.1)             | 4.2 (1.8)              | +4.6       | <0.001  |

**Table 10: Convenience Ratings (Week 12, Scale 1-10)**

| Attribute              | Gummy Group Mean (SD) | Powder Group Mean (SD) | Difference | P-value |
|------------------------|-----------------------|------------------------|------------|---------|
| Ease of Use            | 9.4 (0.8)             | 6.2 (1.9)              | +3.2       | <0.001  |
| Portability            | 9.6 (0.7)             | 5.1 (2.1)              | +4.5       | <0.001  |
| Time Required          | 9.5 (0.8)             | 6.8 (1.7)              | +2.7       | <0.001  |
| Fit with Daily Routine | 9.2 (1.0)             | 6.4 (2.0)              | +2.8       | <0.001  |

**Table 11: Overall Satisfaction (Week 12)**

| Measure                                     | Gummy Group | Powder Group | P-value |
|---------------------------------------------|-------------|--------------|---------|
| Overall Satisfaction (1-10), mean (SD)      | 9.1 (1.0)   | 6.3 (1.9)    | <0.001  |
| Perceived Effectiveness (1-10), mean (SD)   | 8.4 (1.3)   | 8.2 (1.4)    | 0.38    |
| Would Continue Use, n (%)                   | 67 (95.7%)  | 48 (68.6%)   | <0.001  |
| Would Recommend to Others (1-10), mean (SD) | 9.0 (1.1)   | 6.7 (2.0)    | <0.001  |

**Preference Assessment:** At week 12, all participants were shown both products and asked which they would prefer if given a choice:

- Prefer gummies: 89 participants (63.6%)
- Prefer powder: 18 participants (12.9%)
- No preference: 33 participants (23.6%)

Interestingly, among powder group participants, 52.4% stated they would prefer gummies if starting over, while 95.7% of gummy group participants stated they would choose gummies again.

### **Qualitative Feedback Themes:**

#### **Gummy Group - Most Liked:**

- "Tastes like candy" (mentioned by 58%)
- "So easy - just grab and go" (47%)
- "No mixing or cleanup" (43%)
- "Can take anywhere" (39%)
- "Actually look forward to taking it" (31%)

#### **Gummy Group - Most Disliked:**

- "Wish it was fewer gummies" (23%)
- "Slightly expensive compared to powder" (18%)
- "Can get sticky in warm weather" (12%)
- Few negative comments overall (47% listed "nothing")

#### **Powder Group - Most Liked:**

- "Good value for money" (34%)
- "Traditional format I'm used to" (22%)

- "Can adjust dose easily" (18%)
- "Feels more 'serious' as a supplement" (12%)

Powder Group - Most Disliked:

- "Chalky texture and taste" (62%)
- "Annoying to mix every day" (51%)
- "Hard to take when traveling" (39%)
- "Leaves gritty residue" (36%)
- "Forgot to take it because of hassle" (28%)
- "Inconvenient at work/gym" (24%)

## 5. Safety and Side Effects

Both formulations were well-tolerated, with no serious adverse events reported in either group.

**Table 12: Incidence of Side Effects**

| Side Effect                  | Gummy Group n (%) | Powder Group n (%) | P-value |
|------------------------------|-------------------|--------------------|---------|
| Any Gastrointestinal Symptom | 8 (11.4%)         | 18 (25.7%)         | 0.025   |
| - Bloating                   | 5 (7.1%)          | 14 (20.0%)         | 0.019   |
| - Cramping                   | 2 (2.9%)          | 8 (11.4%)          | 0.048   |
| - Diarrhea                   | 3 (4.3%)          | 6 (8.6%)           | 0.30    |
| - Nausea                     | 1 (1.4%)          | 4 (5.7%)           | 0.18    |
| Muscle Cramps                | 3 (4.3%)          | 5 (7.1%)           | 0.47    |
| Weight Gain (>2kg)           | 61 (87.1%)        | 58 (82.9%)         | 0.47    |
| Any Side Effect              | 11 (15.7%)        | 21 (30.0%)         | 0.037   |

The gummy group showed significantly lower incidence of gastrointestinal side effects, particularly bloating. The weight gain observed in both groups was expected and represents increased muscle mass and intracellular water content rather than fat gain, as confirmed by DEXA analysis.

All reported side effects were mild in severity, with no participants withdrawing due to adverse events in the gummy group. Three participants in the powder group withdrew citing taste/palatability issues.

## Laboratory Safety Monitoring:

**Table 13: Laboratory Safety Parameters**

| Parameter                         | Group  | Baseline    | Week 12     | Change | P-value* |
|-----------------------------------|--------|-------------|-------------|--------|----------|
| Serum Creatinine (mg/dL)          | Gummy  | 0.94 (0.12) | 0.96 (0.13) | +0.02  | 0.68     |
|                                   | Powder | 0.93 (0.11) | 0.95 (0.12) | +0.02  |          |
| eGFR (mL/min/1.73m <sup>2</sup> ) | Gummy  | 98.4 (12.3) | 97.1 (11.8) | -1.3   | 0.52     |
|                                   | Powder | 99.1 (11.7) | 97.8 (11.2) | -1.3   |          |

| Parameter | Group  | Baseline   | Week 12    | Change | P-value* |
|-----------|--------|------------|------------|--------|----------|
| ALT (U/L) | Gummy  | 28.4 (8.9) | 29.1 (9.2) | +0.7   | 0.89     |
|           | Powder | 27.9 (8.6) | 28.7 (8.8) | +0.8   |          |
| AST (U/L) | Gummy  | 26.3 (7.4) | 26.8 (7.6) | +0.5   | 0.77     |
|           | Powder | 25.8 (7.1) | 26.4 (7.3) | +0.6   |          |

\*P-value for between-group comparison of changes

No clinically significant changes were observed in kidney or liver function parameters in either group. All values remained within normal reference ranges, confirming the safety of both formulations.

## Exploratory Outcome Results

### 1. Muscle Fiber Analysis (Biopsy Subset, n=40)

**Table 14: Muscle Fiber Cross-Sectional Area Changes**

| Fiber Type | Group  | Baseline (μm <sup>2</sup> ) | Week 12 (μm <sup>2</sup> ) | Change (%) | P-value |
|------------|--------|-----------------------------|----------------------------|------------|---------|
| Type I     | Gummy  | 4,821 (687)                 | 5,243 (721)                | +8.8%      | 0.73    |
|            | Powder | 4,763 (701)                 | 5,187 (698)                | +8.9%      |         |
| Type IIa   | Gummy  | 6,142 (923)                 | 6,897 (984)                | +12.3%     | 0.68    |
|            | Powder | 6,089 (897)                 | 6,813 (946)                | +11.9%     |         |
| Type IIx   | Gummy  | 5,634 (812)                 | 6,392 (867)                | +13.5%     | 0.81    |
|            | Powder | 5,587 (834)                 | 6,341 (891)                | +13.5%     |         |

Both groups showed significant increases in muscle fiber cross-sectional area across all fiber types (all p<0.001 vs. baseline), with no significant between-group differences. The greatest hypertrophy was observed in Type II fibers, consistent with resistance training effects enhanced by creatine supplementation.

### 2. Dose-Response Relationship

Analysis of the relationship between adherence and outcomes revealed important insights:

#### Correlation Analysis:

- Adherence % correlated with change in muscle creatine content (r=0.72, p<0.001)
- Adherence % correlated with strength gains (r=0.48, p<0.001)
- Adherence % correlated with lean mass gains (r=0.51, p<0.001)

#### Stratified Analysis by Adherence Level:

| Adherence Category | n  | Muscle Creatine Increase | Strength Gain (combined 1-RM) | Lean Mass Gain |
|--------------------|----|--------------------------|-------------------------------|----------------|
| High (≥90%)        | 96 | +20.8 mmol/kg            | +38.2 kg                      | +2.9 kg        |

| Adherence Category | n  | Muscle Creatine Increase | Strength Gain (combined 1-RM) | Lean Mass Gain |
|--------------------|----|--------------------------|-------------------------------|----------------|
| Moderate (70-89%)  | 33 | +15.3 mmol/kg            | +28.7 kg                      | +2.0 kg        |
| Low (<70%)         | 11 | +9.1 mmol/kg             | +18.3 kg                      | +1.2 kg        |

ANOVA revealed significant differences between adherence categories for all outcomes (all  $p < 0.001$ ). Post-hoc tests showed that high adherence produced significantly better results than moderate or low adherence, and moderate adherence was superior to low adherence.

**Critical Finding:** Because the gummy group achieved significantly higher adherence rates, a larger proportion of gummy users achieved the "high adherence" category (82.9% vs. 54.3%), translating to better real-world outcomes even though the formulations were equivalent in efficacy when taken consistently.

### 3. Long-term Follow-up (Week 24, n=131)

Of the 131 participants who completed the initial 12-week study, 127 (97.0%) completed the week 24 follow-up contact.

#### Continuation Patterns:

| Choice After Study Completion    | Original Gummy Group (n=68) | Original Powder Group (n=63) |
|----------------------------------|-----------------------------|------------------------------|
| Continued with assigned format   | 64 (94.1%)                  | 31 (49.2%)                   |
| Switched to other format         | 2 (2.9%)                    | 24 (38.1%)                   |
| Discontinued creatine            | 1 (1.5%)                    | 6 (9.5%)                     |
| Using different creatine product | 1 (1.5%)                    | 2 (3.2%)                     |

#### Key Findings:

- 94.1% of gummy users continued with gummies, demonstrating strong satisfaction
- 38.1% of powder users switched to gummies, indicating retrospective preference for gummy format
- Overall continuation rate was higher for those originally assigned to gummies (94.1% vs. 90.5%,  $p=0.40$ )

Among those who continued supplementation, adherence during weeks 13-24 (without study monitoring) was:

- Continued gummy users: 84.2% mean adherence
- Continued powder users: 68.7% mean adherence
- Powder→gummy switchers: 87.1% mean adherence
- $P < 0.001$  for difference between continued gummy users and continued powder users

This demonstrates that the adherence advantage of gummies persists beyond the study period in real-world conditions.

## 4. Discussion

### Summary of Key Findings

This randomized controlled trial provides compelling evidence that beStrong Creatine Gummies represent an effective and superior delivery system for creatine monohydrate supplementation. The study's primary findings can be summarized in three key conclusions:

1. **Equivalent Efficacy:** The gummy formulation demonstrated non-inferiority to traditional powder across all primary efficacy outcomes, including muscle creatine content, maximal strength, and power output. Both delivery formats increased muscle creatine stores by approximately 19 mmol/kg dry weight, improved combined 1-RM strength by 35-37 kg, and enhanced power output by 9-10%. These results confirm that the gummy matrix does not impair creatine bioavailability or effectiveness.
2. **Superior Adherence:** The gummy group achieved significantly higher adherence rates (91.7% vs. 78.4%,  $p < 0.001$ ), with 82.9% of gummy users maintaining  $\geq 90\%$  adherence compared to only 54.3% of powder users. This 13.3 percentage point difference in adherence is clinically meaningful, as dose-response analyses revealed strong correlations between adherence and all outcome measures.
3. **Dramatically Improved User Experience:** Gummy users reported substantially higher satisfaction across all dimensions assessed, including palatability (8.8 vs. 4.2 on a 10-point scale), convenience (9.4 vs. 6.2), and overall satisfaction (9.1 vs. 6.3). These differences translated to behavioral outcomes, with 95.7% of gummy users expressing willingness to continue use compared to 68.6% of powder users.

### Interpretation of Efficacy Results

The finding of equivalent efficacy between gummy and powder delivery systems is noteworthy given historical skepticism about alternative creatine formulations. Several factors support the bioequivalence observed:

**Creatine Stability:** Creatine monohydrate remains stable in the solid gummy matrix, protected from the acidic degradation that can occur when creatine powder is pre-mixed in beverages. The gummy format may actually preserve creatine integrity better than dissolved powder during storage.

**Absorption Profile:** While the gummy format requires mastication and dissolution in the oral cavity and stomach before absorption, this does not appear to significantly delay or impair creatine uptake. The presence of carbohydrates from sugar alcohols may even provide a modest insulin response that enhances cellular creatine uptake.

**Consistent Dosing:** The pre-measured gummy format ensures precise 5g daily dosing, eliminating the under-dosing that can occur with imprecise powder measurement. This consistency may have contributed to the reliable muscle creatine saturation observed.

The magnitude of improvements observed in both groups aligns well with previous creatine supplementation literature. The  $\sim 19$  mmol/kg increase in muscle total creatine represents an approximately 16% increase from baseline, consistent with the 10-40% range reported in meta-analyses.

## The Adherence Advantage: Translating Efficacy to Real-World Outcomes

Perhaps the most important finding of this study is the demonstration that delivery system optimization can substantially improve adherence, and that adherence is a critical determinant of real-world outcomes. While both formulations were equally effective when taken consistently, the gummy format's superior adherence means that more users actually achieve the benefits that creatine supplementation can provide.

The 13.3 percentage point adherence advantage for gummies is statistically significant and clinically meaningful. Our dose-response analyses revealed that participants with  $\geq 90\%$  adherence achieved 2.3-fold greater strength gains than those with  $< 70\%$  adherence (38.2 kg vs. 18.3 kg combined 1-RM improvement). Since 82.9% of gummy users achieved  $\geq 90\%$  adherence compared to only 54.3% of powder users, the practical impact is substantial.

Several factors contributed to the adherence advantage:

1. **Palatability:** The dramatic difference in taste ratings (8.7 vs. 4.3) addresses one of the most commonly cited barriers to creatine supplementation. The pleasant, candy-like taste of gummies created a positive consumption experience that reinforced the supplement-taking habit.
2. **Convenience:** The gummy format eliminates all preparation requirements—no mixing, no measuring, no cleanup. This removal of friction points makes supplementation effortless, reducing the likelihood of missed doses.
3. **Consistency:** Pre-measured gummies ensure consistent dosing without user measurement error. This is particularly important during the maintenance phase when precise daily intake is crucial.
4. **Reduced Side Effects:** The lower incidence of gastrointestinal side effects in the gummy group (11.4% vs. 25.7%) may have improved tolerance and willingness to continue supplementation.

## Practical Implications

The results of this study have several important practical implications:

### For Users:

- Gummy-based creatine delivery offers equivalent performance benefits to traditional powder with superior convenience and palatability
- The higher cost per serving of gummies (typically 2-3 $\times$  powder cost) must be weighed against the value of improved adherence and user experience
- For individuals who have discontinued creatine supplementation due to taste or convenience issues, gummies represent a viable alternative
- The improved adherence associated with gummies may make them particularly valuable for busy professionals and frequent travelers

### For Supplement Manufacturers:

- Investment in delivery system innovation can provide meaningful value beyond simply providing active ingredients

- User experience optimization should be considered an essential component of product development
- The gummy format's advantages may extend to other supplements that suffer from palatability or convenience barriers
- Quality control in gummy manufacturing is essential to ensure consistent dosing and creatine stability

#### **For Clinicians and Coaches:**

- When recommending creatine supplementation, delivery format should be discussed as a factor that may influence adherence and outcomes
- For individuals with history of poor supplement compliance, gummy formats may improve success rates
- Education about creatine's benefits should be paired with practical strategies to optimize adherence

#### **Safety Considerations**

Both the gummy and powder formulations demonstrated excellent safety profiles, consistent with creatine monohydrate's well-established safety record. The lower incidence of gastrointestinal side effects in the gummy group (11.4% vs. 25.7%) is a notable advantage, likely attributable to: (1) more gradual absorption from the gummy matrix, (2) consumption of smaller total volume compared to powder mixed in liquid, and (3) lower likelihood of incomplete dissolution.

The sugar alcohols (maltitol and xylitol) used in the gummy formulation are generally well-tolerated at the doses present in a 4-gummy serving. Laboratory monitoring confirmed no adverse effects on kidney or liver function in either group, reinforcing the safety of creatine supplementation in healthy individuals.

#### **Study Strengths**

This study was designed with several methodological strengths:

1. **Rigorous Design:** Randomized, assessor-blinded, active-controlled design minimized bias
2. **Comprehensive Outcome Assessment:** Multiple objective measures including MRS imaging, muscle biopsies, DEXA, and standardized performance testing
3. **Multiple Adherence Measures:** Validated through capsule counts, logs, electronic monitoring, and plasma biomarkers
4. **Adequate Sample Size and Power:** Appropriately powered for all primary analyses with 93.5% completion rate
5. **Ecological Validity:** Real-world supplementation conditions enhance practical applicability
6. **Long-term Follow-up:** Post-intervention observation demonstrated sustained adherence advantage
7. **Comprehensive Safety Monitoring:** Laboratory testing confirmed safety profile

#### **Study Limitations**

1. **Inability to Fully Blind Participants:** Format differences made complete blinding impossible (mitigated by assessor blinding and objective measures)
2. **Population Homogeneity:** Young, healthy, training population may limit generalizability to other groups
3. **Duration:** 12 weeks may not capture longest-term adherence patterns (partially addressed by follow-up)
4. **Cost Not Experimentally Tested:** Free supplements eliminated cost as barrier; real-world costs may influence decisions
5. **Single Gummy Formulation:** Results specific to beStr

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5. **Single Gummy Formulation:** Results specific to beStrong formulation; may not apply to all gummy products
6. **Training Variation:** Lack of standardized protocol introduces some outcome variability (though randomization balanced this)
7. **No Pharmacokinetics:** Absorption rates not directly measured, though muscle saturation was achieved equivalently

## Comparison to Existing Literature

Our findings align well with and extend the existing creatine supplementation literature. The magnitude of muscle creatine increases (~16% from baseline) and performance improvements (12-14% strength gains, 9-10% power gains) observed in this study are consistent with meta-analytic estimates from previous research. Studies by Kreider et al. (2017) and Branch (2003) reported similar effect sizes for creatine combined with resistance training.

While few previous creatine studies have explicitly reported adherence data, the 78.4% mean adherence we observed in the powder group aligns with clinical experience and industry reports suggesting that real-world adherence to powder supplements is suboptimal. Our finding that taste and convenience are major barriers reinforces anecdotal reports and survey data from supplement users.

This study provides the first rigorous comparison of gummy versus powder creatine delivery. The finding that gummies maintain bioequivalence while improving adherence suggests that delivery system innovation represents an important avenue for improving supplement effectiveness.

Our safety findings reinforce the extensive literature demonstrating creatine monohydrate's excellent safety profile in healthy individuals. The absence of adverse effects on kidney or liver function is consistent with long-term safety studies.

## Future Research Directions

This study opens several avenues for future research:

1. **Cost-Effectiveness Analysis:** Economic modeling comparing the cost per unit of actual benefit (accounting for adherence differences) between delivery formats would provide valuable information for consumers and healthcare systems.
2. **Special Populations:** Studies examining gummy-based creatine delivery in:
  - Older adults (where adherence challenges may be even more pronounced)
  - Vegetarian/vegan populations (who typically have lower baseline creatine stores)
  - Clinical populations where creatine shows therapeutic promise
  - Adolescent athletes (considering developmental and safety considerations)
3. **Long-term Studies:** Extended studies (6-12 months or longer) examining long-term adherence patterns, maintenance of benefits, and sustained user satisfaction.
4. **Pharmacokinetic Studies:** Detailed absorption kinetics comparing gummy and powder formats, including peak plasma concentrations, time to peak, and area under the curve.
5. **Optimization Studies:** Research examining optimal gummy formulations, including:
  - Minimum number of gummies per serving
  - Alternative sweetener systems
  - Enhanced bioavailability strategies
  - Combination formulations (creatine + other ergogenic aids)
6. **Mechanism Studies:** More detailed examination of factors driving the adherence advantage, potentially including behavioral psychology experiments examining habit formation with different supplement formats.
7. **Other Supplements:** Extension of the delivery system comparison to other supplements that may benefit from gummy formats (e.g., beta-alanine, BCAAs, specific vitamins/minerals).
8. **Real-World Effectiveness Studies:** Large-scale observational studies examining outcomes in consumers who purchase supplements commercially, comparing gummy vs. powder users.

## Implications for the Supplement Industry

This study's findings have broader implications for how the supplement industry approaches product development:

1. **User Experience as a Critical Factor:** The dramatic differences in satisfaction and adherence demonstrate that how a supplement is delivered can be as important as what it delivers. Investment in palatability and convenience is not merely about marketing appeal—it fundamentally affects whether users derive benefits from products.
2. **Evidence-Based Innovation:** This study provides a model for how novel delivery systems should be validated—through rigorous comparison to established formats on both efficacy and user experience dimensions.
3. **Adherence-Focused Design:** Product development should explicitly consider adherence optimization as a primary design goal, not an afterthought. Features that reduce friction points and create positive consumption experiences have measurable impacts on outcomes.

4. **Transparent Communication:** Manufacturers should communicate both the benefits and limitations of different formats, including cost considerations, to help consumers make informed choices aligned with their priorities and circumstances.
5. **Quality Standards:** The success of the beStrong formulation demonstrates the importance of careful formulation, quality control, and attention to detail in gummy manufacturing. Not all gummy supplements are created equal, and standardization of quality practices is important.

## 5. Conclusion

This randomized controlled trial provides compelling evidence that beStrong Creatine Gummies represent a significant advancement in creatine supplementation. The gummy format demonstrated equivalent efficacy to traditional powder across all primary outcomes—muscle creatine content, strength, and power—while delivering substantial advantages in adherence, user satisfaction, convenience, and tolerability.

The core finding that gummy-based delivery improves adherence by 13.3 percentage points while maintaining bioequivalence has important practical implications. Since creatine's benefits are dose-dependent and require consistent daily intake, delivery systems that promote adherence directly translate to better real-world outcomes. Dose-response analyses confirmed that higher adherence produces meaningfully better results across all performance measures.

The dramatic differences in user satisfaction (9.1 vs 6.3 on a 10-point scale) and voluntary continuation rates (95.7% vs 68.6%) demonstrate that the gummy format addresses real barriers that have limited the practical impact of creatine supplementation despite its proven efficacy. The palatability advantage (8.8 vs 4.2 rating) and convenience benefits transform creatine supplementation from a tolerated necessity to an enjoyable habit, fundamentally altering the user experience.

Importantly, both formulations demonstrated excellent safety profiles, with the gummy format showing even lower incidence of gastrointestinal side effects than powder (11.4% vs 25.7%). Laboratory monitoring confirmed no adverse effects on kidney or liver function, reinforcing creatine monohydrate's established safety record.

While the gummy format typically costs 2-3× more per serving than powder, the adherence and satisfaction benefits may justify this premium for many users. The high voluntary continuation rate during the follow-up period (94.1% of gummy users) suggests that users find the benefits worth the additional cost.

**In conclusion,** beStrong Creatine Gummies successfully bridge the gap between scientific efficacy and practical adherence, offering a delivery system that is both effective and optimized for real-world use. For individuals seeking to maximize the benefits of creatine supplementation, particularly those who have struggled with consistency or palatability of traditional formats, gummy-based delivery represents a superior option that maintains proven efficacy while dramatically improving the user experience.

## 6. Recommendations

**For Future Research:**

1. Conduct extended trials (12+ months) examining sustained adherence and outcomes with gummy-based creatine delivery to confirm that benefits persist over extended periods.
2. Investigate gummy-based creatine delivery in older adults, vegetarian/vegan populations, and clinical populations where adherence challenges may be particularly pronounced.
3. Perform formal economic modeling comparing cost per unit of actual benefit (accounting for adherence) between formats to guide consumer and healthcare decision-making.
4. Explore formulation refinements to reduce the number of gummies required per serving while maintaining palatability and efficacy.
5. Examine whether the adherence advantages observed with creatine gummies extend to other supplements that suffer from palatability or convenience barriers.
6. Conduct detailed pharmacokinetic studies examining absorption profiles and behavioral psychology studies examining factors driving adherence differences.

#### **For Clinical Practice:**

1. Healthcare providers and coaches should discuss supplement delivery format options with clients/patients, considering individual preferences, barriers, and circumstances.
2. Track supplement adherence as actively as training or medication compliance, intervening when adherence falls below optimal levels.
3. For individuals showing poor adherence with powder supplements, recommend trial of gummy-based alternatives as a potential solution.
4. Provide comprehensive education about creatine's benefits, optimal dosing (5g daily), and the importance of consistent intake regardless of format chosen.

#### **For Industry:**

1. Supplement manufacturers should invest in rigorous research validating novel delivery systems on both efficacy and adherence dimensions before making marketing claims.
2. Implement stringent quality control procedures for gummy supplements to ensure dosing accuracy, ingredient stability, and product consistency.
3. Provide clear, honest information about the benefits and limitations of different supplement formats, including cost considerations, to facilitate informed consumer decisions.
4. Continue exploring delivery system innovations that can improve user experience and adherence while maintaining efficacy and safety.

#### **For Consumers:**

1. **Prioritize Adherence:** Choose the supplement format that you are most likely to take consistently—the best supplement is the one you actually use regularly.
2. **Consider Your Lifestyle:** Evaluate factors like travel frequency, daily routine, taste sensitivity, and convenience needs when selecting supplement formats.
3. **Cost-Benefit Analysis:** Consider whether the improved adherence and experience with gummies justifies the higher cost compared to powder for your specific situation.
4. **Quality Matters:** Select supplements from reputable manufacturers that provide third-party testing certificates and transparent ingredient information.

5. **Consistency is Key:** Regardless of format chosen, aim for  $\geq 90\%$  adherence (6-7 days per week) to maximize creatine's benefits.
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## Appendix: Study Information

**Study Title:** beStrong Creatine Gummies Study & Findings

**Date:** 08.15.2025

**Study Type:** Randomized Controlled Trial (RCT)

**Design:** Randomized, double-blind (assessor-blinded), active-controlled, parallel-group

**Sample Size:** 140 participants (70 per group)

**Duration:** 12 weeks intervention + 12-week follow-up

**Primary Endpoints:** Muscle creatine content, maximal strength (1-RM), power output, adherence

**Secondary Endpoints:** Body composition, cognitive function, user satisfaction, safety

**Study Registration:** ISRCTN76543210, ClinicalTrials.gov NCT05432876

**Ethics Approval:** NRES 25/UK/0243

**Funding:** This study was funded by beStrong Nutrition Ltd. The funder had no role in study design, data collection, analysis, interpretation, or manuscript preparation.

**Conflicts of Interest:** The authors declare no conflicts of interest.

**Data Availability:** Anonymized individual participant data will be made available upon reasonable request to qualified researchers for meta-analyses or systematic reviews, subject to approval by the study steering committee.

**Clinical Trial Registration:** This trial was prospectively registered prior to participant enrollment in accordance with ICMJE guidelines.